HUMAN-NATURE INTERACTIONS: PERSPECTIVES ON CONCEPTUAL AND METHODOLOGICAL ISSUES

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HUMAN-NATURE INTERACTIONS: PERSPECTIVES ON CONCEPTUAL AND METHODOLOGICAL ISSUES

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Table of Contents

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Editorial: Human-Nature Interactions: Perspectives on Conceptual and Methodological Issues

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Editorial on the Research Topic

Human-Nature Interactions: Perspectives on Conceptual and Methodological Issues

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Urban agglomerations expose citizens to ever-increasing risks from heat, air pollution, noise stress, and reduced nature connectedness. Concurrently, accumulating evidence suggests various health benefits by exposure to urban natural spaces (World Health Organization, 2016a; Bratman et al., 2019). Existing research suggests an array of benefits of contact with nature which are linked to physical activity (e.g., green exercise), active travel, and residential proximity to greenspace. Psychological benefits appear to be related to mood, well-being, attention and pro-environmental behavior; physiological benefits have been described in terms of increased physical activity, improved cardiovascular parameters, reduced stress hormones, and enhanced immune resources (Bowler et al., 2010; Li, 2010; Park et al., 2010; Calogiuri and Chroni, 2014; Hartig et al., 2014; van den Bosch and Sang, 2017).

Nature offers a low-cost non-invasive solution for mental health and well-being with the potential to reduce inequities. This has never been so relevant. COVID-19 related restrictions on mobility and associated reduced (or lack of) access to many recreational venues, has meant that engaging with nature, by visiting nearby natural environments (Samuelsson et al., 2020) or through home gardening (Walljasper and Polansek, 2020) has been an important means of staying active and managing stress—in some case also to mitigate food insecurity. Technology, especially emerging technologies such as virtual reality (VR), can also facilitate human-(virtual) nature interactions when contact with real nature is not possible (Litleskare et al., 2020).

Environmental psychology has helped us to understand human-nature interactions from a transactional perspective (Gifford, 2013). Ecosystems services have been applied to explain the benefits and risks of such interactions (Bratman et al., 2019). More recently, *nature-based solutions* (NBS) have come to the fore supported by the EU Biodiversity strategy 2030, UN Global Compact and the IUCN global standard for NBS. There is a growing scientific imperative in achieving consensus on the optimum measures, methodological approaches, theoretical frameworks, and concepts to enhance our understanding of human-nature interactions (Frantzeskaki, 2019). The race for upscaling and proliferation of NBS has commenced and yet the speed of advancement of conceptual understanding and methodological rigor lags behind. Despite more than three decades of research since the advent of the *biophilia* hypothesis, researchers' conclusions have been limited by methodological challenges. Few studies have employed measures that are directly comparable with national or international surveys (e.g., WHO-5). Theoretical assumptions from environmental psychology have not been readily supported by models based on biological plausibility or neural implementation. A range of methodological approaches in the assessment of predisposing factors including nature connectedness and prior experience has limited the capacity of systematic reviews to conduct reliable comparisons (Lahart et al., 2019). Standardization of measures and conceptual clarity among researchers would facilitate more robust research, cross-cultural comparisons and provide clearer evidence for the future decisions on investment in nature-based solutions with the capacity to address many societal challenges.

In launching this Research Topic, our objective was to capture contemporary perspectives on the conceptualization and measurement of human-nature interactions, and advance future research perspectives. The ubiquitous nature of the challenge is exemplified by a diverse and expansive list of countries of our contributors, which ranges among 15 different countries including Australia, Brazil, Denmark, Finland, Germany, Ireland, Norway, Peru, Portugal, Singapore, South Africa, Spain, Switzerland, the UK, and the USA. Twenty articles were included in the collection. These included an array of approaches, with nine original research articles, two brief research report articles, four perspective articles, two reviews, and three systematic reviews. Many provide novel viewpoints in our understanding of human-nature interactions, in relation to both, the effects of being in contact with nature and potential underlying mechanisms explaining the relationship. More specifically, the articles included in this collection have investigated the extent to which exposure to nature can affect indices of physical and mental health (Berry et al.; Gritzka et al.; Mygind et al.), psychophysiological parameters (Becker et al.; Browning, Mimnaugh et al.; Hunter et al.; Litleskare and Calogiuri; Reeves et al.), cognitive restoration (Olszewska-Guizzo et al.; Stevenson et al.), and environmental attitudes and behaviors (Rosa and Collado). Two articles evaluated "best-dose" of nature exposure, i.e., the most effective amount of time required to obtain health benefits (Hunter et al.; Meredith et al.).

Several of the included articles have investigated or discussed possible explanations for the health and restorative benefits of interacting with nature. These included studies on brain activity associated with perception of natural environments (Mahamane et al.; Olszewska-Guizzo et al.; Reeves et al.), the impact of scene oscillations on psychological responses to exposure to virtual nature (Litleskare and Calogiuri), and how eye movements contribute to explain restorative processes (Stevenson et al.). Two studies have investigated the impact of being exposed to natural environments on health-related behaviors that may, in turn, contribute explaining the health effects of interacting with nature; these included physical activity (Becker et al.) and healthy decision-making (Berry et al.). One article proposed a theoretical framework that can be adopted to conceptualize the complex human-nature interaction (Brymer et al.). Two articles examined the relationship between the concepts of nature connectedness and social relational values (Kleespies and Dierkes) or between the concepts of nature connectedness and emotions (Petersen et al.), whereas Render et al. explored the association between individuals' personality and their choice of work environment. Other topics included related to challenges encountered by interdisciplinary research groups (Berry et al.), the conditions of captive amphibians (Measey et al.), and the concept of place identity (Peng et al.) and vulnerability (Tallman et al.).

This Research Topic highlighted the growing interest in studying nature effects on cognition through use of cutting-edge technologies and instruments, such as virtual reality (VR) and measurements of brain activity. This is encouraging, as the hope is that using more immersive, yet experimentally controlled, exposure to natural environments increasing the precision that will allow comparison of different environment exposures (e.g., different types of nature, built environments). Moreover, modern cognitive neuroscience approaches such as electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) may be more useful in indicating the mechanism underlying these nature benefits, by indicating how different brain regions are engaged between the different experimental conditions (e.g., see Madan et al., 2019, for further background). In the present Research Topic, several studies were based on this approach, using VR or 3D imaging to expose participants to different environments (Browning, Mimnaugh et al.; Litleskare and Calogiuri; Olszewska-Guizzo et al.), and/or performed objective measurements such as EEG assessments of brain activity (Mahamane et al.; Olszewska-Guizzo et al.; Reeves et al.), biomarkers of stress (Becker et al.; Hunter et al.; Reeves et al.), and assessments by mobile eye-tracker (Stevenson et al.). Innovative instruments and methodologies were also represented, with one study involving a novel approach to implement "self-managed" nature experiences interventions in the context of daily life (Hunter et al.) and another examining the effectiveness of using a novel low-cost wearable technology to conduct in-loco assessments of brain activity and biomarkers of stress (Reeves et al.).

The rationale for this Research Topic was to advance the methodological rigor in the field and the research appears to have supported the need for such an approach. For example, quality of the evidence was often deemed low in both systematic reviews (Gritzka et al.; Mygind et al.) and this had recently been reported in the broader literature (Lahart et al., 2019). This limiting factor inhibited both analyses and effect sizes were thus not calculated in either study. With this in mind and the aforementioned discourse, we present our recommendations for future research.

RECOMMENDATIONS

On the base of wider literature and emerging knowledge in this field, as well as the new knowledge generated through the articles included in this Research Topic, we highlight the following recommendations for future research:

- *Nature experiences during COVID19 pandemic*—The COVID19 global pandemic brought to the fore the need to increase both the access and availability of nature in urban areas for multifunctional inter-generational social, physical, and mental health (Nieuwenhuijsen, 2020). One learning point for the field is that the transactional viewpoint of ecosystem services (for health) does not adequately address the complex interactions between humans and nature. Investment in nature-based solutions by the EU, for example, highlights that transdisciplinary approaches more readily capture for the potential reciprocal benefits. Within the Research Topic a wealth of theoretical approaches had been applied (e.g., ecological systems) which pivoted beyond the traditional dichotomous approach of Stress Reduction Theory and Attention Restoration Theory. As the published papers in this Research Topic have demonstrated, theory-driven research using diverse explanatory frameworks are recommended to enable the research of today to resonate far into the future.
- *Nature Exposure and Experience*—A parsimonious approach focused on dose-response effects may overlook the role of the participants' attention or mindset during nature exposure. To this end, Bratman et al. (2019) refer to the nature experience as comprising both "dose" and "interaction"; i.e., the specific ways in which people interact with nature may account for differential impacts of nature exposure on health-related outcomes. Nature connectedness is a key variable that requires further insight-do we need an urban nature connectedness construct? Furthermore, there is a need to account for other factors including natural environment quality (a potential factor of inequality, World Health Organization, 2016b), the attention of the participant and their perception of the setting.
- *Immersive technology to enhance methodological rigor*—Use of immersive technology such as virtual reality (VR) and, especially, immersive-virtual environments (IVE) offers great opportunities for conduction experiments in highly controlled conditions. While we encourage researchers to make use of this technology in experimental design to enhance methodological rigor, we also warn about challenges associated with this technology. While VR and IVE technology can provide more vivid experiences of nature as compared to non-immersive virtual exposure (e.g., videos or pictures), recent analyses show that exposure to virtual nature provides psychological responses to a lesser extent than real nature (Browning et al., 2020). This needs to be taken into account when interpreting findings of experiments using environmental exposure via VR or IVE. At the same time, we encourage more studies that aim to understand how to improve the quality of virtual nature experiences.
- *Technological nature to promote and augment human-nature interactions*—Recently attention has been drawn to the role technological nature (especially in form VR, augmented reality, and mobile applications) in promoting and augmenting human-nature interactions, particularly among groups of individuals with limited access to real nature (Litleskare et al., 2020). Studies in this field are extremely scarce, thus we encourage researchers to explore the effectiveness of different approaches as well as their underlying mechanisms.
- *Multidimensional health*—An array of methods have been employed in an attempt to comprehensively account for the possible positive and negative impacts of human nature interactions. Subjective scales, objective markers (e.g., EEG), and biomarkers (e.g., cortisol) can provide converging evidence for the impact and will potentially expand the range of factors to be considered in the future. For instance, the construct of psychological resilience, has rarely been subject to study by researchers in this field despite the obvious overlap with the concept of resilience in natural systems. A broad view of health could also enable greater generalizability across settings from the workplace to the classroom, to the urban and rural communities supported by a broad consensus or standardization in the measures of the common constructs and outcomes.
- *Interdisciplinary and Transdisciplinary*—The evidence presented in this Research Topic and our recommendations are not specific to one field or discipline but have implications across the broader field beyond environmental psychology. Environmental psychology, after four decades could benefit from a reset on the approaches required to address the ever-pressing wicked problems of climate change, biodiversity deficit, environmental degradation, rapid urbanization, and global pandemics.
- Our actions, decisions and omissions are so closely intertwined with ecological effects that they can hardly be considered separately (Stokols, 2018). Nature provides a potential low stigma and low risk intervention, and the benefits for human and environmental health are potentially reciprocal. These complex inter-relationships requires theory driven questions, sophisticated methods and complex analyses. By advancing the concepts and methods a window of opportunity opens for human nature interactions to be more clearly elucidated.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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BRIEF RESEARCH REPORT
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Effects of 3D Contemplative Landscape Videos on Brain Activity in a Passive Exposure EEG Experiment

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Background: Studies on Contemplative Landscapes (CL) show that not only do they have high ecological and visual values and are preferred by a majority of people, but they also can be beneficial to our mental health and well-being. Physical attributes of CL have been studied and operationalized, which has led to the development of the psychometric measurement tool called the Contemplative Landscape Questionnaire (CLQ) (1).

Objectives: In the present study, we applied an experimental approach to the analysis of CL. We hypothesized that, when compared to Non-Contemplative Landscapes (NCL), they would induce higher frontal alpha power asymmetry, higher temporal beta power asymmetry and lower bilateral frontal beta power.

Methods: Thirty-two healthy individuals (12 female) took part in the study. During the experimental protocol, participants were asked to passively view 12 landscapes, six CL and six NCL, while continuous EEG was recorded in a within-subjects design.

Results: We found significantly increased power in the beta frequency band of the right temporal brain regions in the viewings of CL compared to NCL

Conclusions: The findings suggest that Contemplative Landscapes capture more visual, stimuli-driven attention from the viewers and can be linked with switching attention systems (described in Attention Restoration Theory), which is compatible with a stress reduction mechanism.

Keywords: contemplative, landscape, ART, design, well-being, mental health, EEG

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INTRODUCTION

Current trends in landscape architecture and urban planning show the increasing demand for space design solutions that will achieve both environmental and social benefits. Therefore, the concept of Evidence-Based Design (EBD) has emerged, attracting increasingly more attention of researchers and designers, as well as decision makers (2–5). The research attempts, within the EBD, to emphasize credible evidence to inform design of green open spaces, especially in the urban context, to improve people's health and well-being. This emerging field includes, among other areas of expertise, the methods of psychology and neuroscience.

Accordingly, our experiment aims at examining the potential differences in brain activity patterns between the processing of landscapes identified as Contemplative (CL) and Non-Contemplative Landscapes (NCL). CL are green outdoor settings, which, according to the CLQ, are characterized by a combination of multiple features (long vistas, lush seemingly-wild vegetation, the presence of symbolic elements, and smooth landforms, among others) and scored above 4.5 points in a 1-6 point scale, which means the explicit accumulation of the key features (1). NCL, on the other hand, are green outdoor settings that scored lower than 3.0 points on the same scale. The construct of CL may be linked with the Attention Restoration Theory (ART) with a so-called restorative effect of exposure to natural environments, which can reduce stress and mental fatigue, improve positive emotions and promote a sensation of well-being (6–8). These effects may be indirectly linked with the therapeutical benefits of natural environments in the treatment of psychiatric issues such as bipolar disorder and ADHD, among others; however, there is no enough evidence on that yet (9). Moreover, ART did not attempt to specify and systematize physical attributes of restorative environments, while the CL approach focuses on specific features of the green outdoor landscapes that may trigger these effects.

Environmental psychologists set the concept of attention restoration against the concepts of stress and mental fatigue (7, 8). Accordingly, research shows that the relaxing benefits of natural landscapes can stimulate the patterns of brain activity associated with positive emotional states (10, 11). One of such states is characterized by lower alpha power on the left frontal lobe in comparison to the right. This pattern would be followed with lower bilateral frontal beta power [e.g., (12, 13)]. Another possible state is greater beta activity in the right temporal regions as an index of visual attention (14, 15) and a bottom-up, stimulus-driven attention (16).

In the context of the present experiment, we hypothesized that CL would induce higher frontal alpha power asymmetry, higher temporal beta power asymmetry and lower bilateral frontal beta power, when compared to NCL. This could suggest that being exposed to CL may induce the pattern associated with positive emotional states and involuntary, effortless attention, as predicted by ART.

METHODS

Participants

Thirty-two participants (12 female) were recruited among students and researchers of the University of Porto and took part in the study. Twenty-six were Portuguese, four Polish, one Russian, one American, and one Greek. The mean age of the participants was 27 y.o. (*SD* = 6.5 y.o.). All had completed at least 12 years of formal education. Four participants were left-handed and their recordings were included as this would not significantly change the results of the experiment.

All participants had normal, or corrected to normal, vision. None reported psychiatric, neurological or cognitive diseases. Also, none of the participants reported use of medication that could alter the functioning of the Central Nervous System at the time of the experiment. The existence of a pacemaker, intracranial electrodes, implanted defibrillator or plates, otologic surgery in the last 12 months, or any dentures, were additional exclusion criteria. None of the recruited participants was excluded. All participants signed the informed consent form and filled in the socio-demographic questionnaire.

Materials

Stimuli

Twelve 3D fixed-angle videos representing landscape images that were previously rated by experts (landscape architecture and urban ecology academics), based on the CLQ (1) including six CL and six NCL videos. Each of the videos was 20 s long.

The recorded video format was TS(AVC)("*.m2ts") with a frame size of 1920 × 1080 pixels, 50i frame speed and 16:9 aspect ratio, recorded with a Sony™ HDR-TD30 camcorder. The videos were converted, using the Magix™ Movie Edit Pro 2015 software, to the mp4 file format with side-by-side composition of images, preserving the initial image resolution and aspect ratio. The individual landscape videos were mounted into two single video presentations of 2 min each, in order to obtain a block design protocol. The videos were displayed using the free software Bino 3-D video player, in the Left/Right and Open GL mode. This allowed the display of the entire set of videos for each condition by the projector (DepthQ HDs3D-1) on the screen (2,440 × 1,800 mm). To see the depth of the image, each subject wore Nvidia 3D shutter glasses, which were connected to the PC and received the infrared signal by the IR 3D emitter.

EEG Apparatus

The EEG data were collected using an eight-channel electroencephalographic amplifier, Enobio model with dry electrodes, placed on a neoprene headcap. The device is wireless (operating with Bluetooth) with a Li-Ion battery, and connected to a laptop through the NIC 1.2 software (17).

Procedure

Data Collection

Data acquisition took place in a quiet room on the university premises. All electronic devices in the room were switched off, except the stimulation and EEG recording systems, to reduce all possible external electromagnetic artifacts. The experiment was prepared in a block design, where subjects were instructed to passively observe the videos of the selected landscapes. The videos were organized in two blocks—CL and NCL—counterbalanced across participants to control for order effects and displayed while their EEG activity was being recorded. Baseline recordings (BL) of 3 min were performed for each subject in resting state (looking at the empty screen with eyes open) before displaying the blocks of stimuli. Event markers at the beginning of the BL and at the onset of each new landscape were manually inserted in the EEG recordings.

The scalp of the participant was cleaned with a cotton-pad wetted with ethylic alcohol, with special attention to the areas where the electrodes were placed. Eight active dry electrodes were placed on the Enobio cap according to the International Position System 10–20 at the AF7, AF8, Fz, T7, Cz, T8, P3, and P4 referenced to an electrode placed at the right mastoid (RM). The electrode locations were selected according to the areas of interest that were identified in the literature (12–14). Electrode impedances were checked and kept below 20 kΩ at all sites, which is considered an acceptable value for dry electrodes (18, 19). The EEG signal was acquired in the 0–250 Hz band at a 500 Hz sampling rate. Line noise interference was reduced using a notch filter of 50 Hz.

Subjects were seated on a fixed chair, placed 2 m in front of the screen. The 3D shutter glasses were put on the participants' eyes without interfering with the cap, cables, or electrodes. In the case of subjects wearing correction glasses, they were kept under the 3D shutter glasses.

Subjects were instructed to passively watch the videos of each landscape. Each subject was also informed about the three parts of the experiment and their duration: baseline recording at the beginning and CL/NCL landscapes presented in a counterbalanced order, with a fixation cross of 5 s before the beginning of each block. A schematic of the data recording procedure is displayed in **Figure 1**.

Subjects were instructed to sit still on the chair, avoid head, and body movements, and to focus the eye gaze on the center of the screen to prevent eye movement artifacts. They were also instructed to slightly open the mouth and reduce blinking as much as possible to diminish muscle artifacts.

Data Processing and Analysis

Data analysis was performed using MATLAB 5.3 with EEGLAB toolbox (20). The recorded EEG data was downsampled to 250 Hz and re-referenced to the average of all electrodes.

Data was then segmented into epochs of 20 s corresponding to each landscape for CL and NCL conditions. Regarding BL, a segment of 20 s was extracted between 120 and 140 s after the beginning of the recording to ensure the same duration of the segments.

After visual inspection, none of the segments was excluded due to defective signal quality.

Band-pass filters were then applied to all segments, targeting the frequencies of interest: alpha (7.5–14 Hz) and beta (14–30 Hz). As a result, we obtained two files per subject and per condition, each containing one of the frequencies described above. The mean absolute power was computed for each electrode as the average of the square voltage amplitude at each time point (μV^2). Power values were log transformed in order to normalize their distributions, and asymmetries between brain hemispheres per EEG band were computed by applying the formula log(R)-log(L), where R is the power of a particular EEG band on the right hemisphere and L is the power on the left hemisphere. This procedure has been widely used in studies on asymmetries [e.g., (12, 21)]. The score is zero (no asymmetry) when left and right power is equal, whereas increased right over left activity results in higher scores (22). In sum, and in order to address our hypotheses, we obtained measures for: asymmetry between right and left hemisphere for alpha and beta frequency bands at the frontal and temporal electrode locations; and also, mean absolute power for beta frequency band at the frontal electrode locations (AF7 and AF8).

Statistical Analysis

Two separated Repeated Measures ANOVA were conducted with *Condition* as within-subjects factor (BL, CL, NCL) and alpha frontal (AF7, AF8) asymmetry and beta temporal (T7, T8) asymmetry as dependent variables. A two-way Repeated Measures ANOVA with *Condition* and *Electrode Site* (AF7, AF8) as within-subjects factors and mean frontal beta power

FIGURE 1 | Task design and stimulus presentation for the resting state (BL), contemplative condition (CL), and non-contemplative condition (NCL); photo credits A. Olszewska-Guizzo.

as dependent variable. Post-hoc multiple comparison tests were performed using the Holm-Sidak method (23) when the effect of condition was statistically significant ($\alpha = 0.05$). Mauchly's tests indicated no sphericity violations, as their results were not significant (all $p > 0.05$).

RESULTS

Frontal Alpha Asymmetry

Repeated-measures ANOVA revealed that the experimental *Condition* had no significant effect on frontal alpha asymmetry, $F_{(2, 62)} = 1.51$, $p = 0.229$, $\eta^2 = 0.81$. The result remains insignificant after rejecting left-handed: $F_{(2, 54)} = 2.51$, $p = 0.090$, $\eta^2 = 0.80$.

Temporal Beta Asymmetry

Repeated-measures ANOVA revealed that the experimental *Condition* had a significant effect on temporal beta asymmetry, $F_{(2, 62)} = 24.2$, $p < 0.001$, $\eta^2 = 0.72$. The differences in the mean values of temporal beta asymmetry between the resting state ($M_{BL} = -0.016$, $SD = 0.208$), when the subjects were viewing the Contemplative Landscapes ($M_{CL} = 0.156$, $SD = 0.199$) and when they were viewing the Non-Contemplative Landscapes ($M_{NCL} = 0.093$, $SD = 0.167$) were greater than what would be expected by chance and *post-hoc* analyses indicated significant differences between all pairs: NCL and BL ($p < 0.001$), CL and NCL ($p = 0.015$) and between CL and BL ($p < 0.001$).

As mean beta power asymmetry > 0, participants showed higher beta power on the right temporal side of the brain than the left temporal side (**Figure 2**).

These results remained similarly significant after rejection of left-handed participants: $F_{(2, 54)} = 20.4$, $p < 0.001$, $\eta^2 = 0.71$. Also, post-hoc analyses revealed significant differences between all pairs of conditions: NCL and BL ($p < 0.001$), CL and NCL ($p = 0.024$) and between CL and BL ($p < 0.001$).

Mean Frontal Beta Power

The Two–Way repeated measures ANOVA revealed a main effect of *Electrode Site*, $F_{(1, 31)} = 249.7$, $p < 0.001$, $\eta^2 electrode = 0.59$, with lower frontal beta power on the AF7 ($M = -0.035$, $SD = 0.271$) than on the AF8 electrode ($M = 0.627$, $SD = 0.283$). A main effect was also found of *Condition*, $F_{(2, 62)} = 205.3$, $p < 0.001$, $\eta^2 Condition = 0.16$, with higher frontal beta power for BL ($M_{BL} = 0.543$, $SD = 0.368$), whereas subjects showed similar values for CL and NCL ($M_{CL} = 0.165$, $SD = 0.425$; $M_{NCL} = 0.181$, $SD = 0.397$). The interaction between *Electrode Site* and *Condition* revealed no effect, $F_{(2, 62)} = 2.59$, $p = 0.082$.

The *post-hoc* analyses using the Holm-Sidak method revealed that there was no significant difference between the CL and NCL condition, on both AF7 ($p = 0.183$) and AF8 electrodes ($p = 0.806$). On the contrary, the test revealed that the frontal beta power was significantly different on both AF7 and AF8 electrodes when comparing BL with CL and NCL conditions (both $p < 0.001$).

Rejecting left-handed participants did not change these results significantly: *Electrode Site* $F_{(1, 27)} = 226.6$, $p < 0.001$, $\eta^2 electrode = 0.57$; *Condition*, $F_{(2, 54)} = 159.7$, $p < 0.001$, $\eta^2 condition = 0.17$.

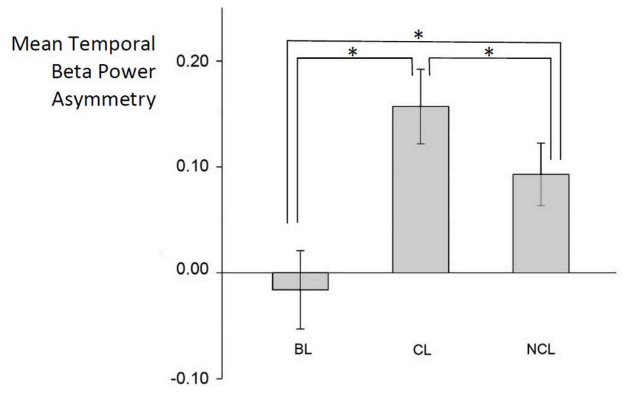

FIGURE 2 | Differences in temporal beta asymmetry between resting state (BL), contemplative (CL), and non- contemplative (NCL) conditions. *symbol signifies $p < 0.001$.

DISCUSSION

This study builds on the previously operationalized Contemplative Landscape Model (1). We intended to examine the effects of CL and NCL on brain activation patterns using experimental neurophysiology. We hypothesized that CL would induce lower alpha power in the left hemisphere, higher beta power on the right temporal regions and lower bilateral frontal beta would induce higher frontal alpha power asymmetry, higher temporal beta power asymmetry and lower bilateral frontal beta power, when compared to the NCL.

Our results revealed two main findings that support one of the hypotheses: we found greater beta power on the right temporal lobe, as expected, but we found no effects of condition on alpha power asymmetry, contrary to our prediction. Regarding frontal beta power, we found higher values of beta power on the baseline and no differences between CL and NCL landscapes, as we would expect.

Considering the temporal beta power asymmetry, our finding suggests a general activation of the right temporal areas of the brain while watching both CL and NCL scenes when compared to the baseline. This pattern was significantly stronger in the case of CL when compared to NCL, which may suggest that participants were more intensely perceiving the holistic aspect of the displayed landscapes, recognizing, and processing the general spatial relationships between its elements, e.g., perceiving a forest rather than a single tree. This brain activity pattern could also be associated with bottom-up, stimuli driven attention directed at the salient stimuli, which can be linked to 'fascination' (a key-component of restorative environment) (6, 16).

The right temporal areas of the brain are, among other functions, responsible for global visual attention (14, 15), visual information interpretation and memory of pictures, visual scenes, and familiar faces (24). The difference between CL and

NCL suggests that contemplative landscapes capture more of this attention pattern from the viewers.

According to the Attention Restoration Theory (ART), attention consists of two components: "involuntary attention, where attention is captured by inherently intriguing or important stimuli, and voluntary or directed attention, where attention is directed by cognitive-control processes" (6). Directed attention includes all the tasks requiring mental effort, and after some time it induces mental fatigue in people. Attention may be "restored" by switching to involuntary attention, which is associated with exposure to natural environments. A similar model of attention mechanisms was presented by Corbetta and colleagues as goal-directed rather than stimulus driven attention. The latter is a bottom-up system oriented at perception of behaviourally relevant stimuli, which works as a "circuit breaker" for the top-down attention system (16). It seems that the pattern of brain activity induced by both CL and NCL in this experiment (the greater right temporal beta activity) can be associated with the involuntary attention mechanism, but in the case of CL scenes, this effect was more intense.

Regarding frontal alpha power asymmetry and frontal bilateral beta power, although our hypotheses were not confirmed, further research should address these issues, and thus extend the amount of research-based evidence on the effects of the visual quality of landscapes on brain activity. The presented study represents the first attempt to examine how the CL affect neural activation patterns. As an exploratory study, it has some limitations that future studies should consider, i.e., the sample size, although optimal for most typical EEG studies, can be considered relatively small given the low signal-to-noise ratio present in the recordings. Also, further studies could be conducted in natural environments despite the challenges posed by the level of background noise present in such environments.

Findings such as the ones in this study, linking neuroscience to landscape architecture, may shed light on the influences of landscape design on brain and mental states, with potential benefits for mental health and well-being. As an interface research field, studies crossing neuroscience and architecture will face several methodological challenges, but experiments like this one are important to pave the way.

ETHICS STATEMENT

The presented work is part of the PhD research conducted in accordance with the Guide for Research Ethics Committee Members available at https://sigarra.up.pt/up. The research project has been approved by the Scientific Council of the Faculty of Science at University of Porto.

All participants signed an informed consent form and detailed participant information sheets that described the aims, methods, and implications of the research, the nature of the participation and any benefits, risks, or discomfort that might ensue; explicitly stated that participation is voluntary and that anyone has the right to refuse to participate and to withdraw their participation or data at any time—without any consequences; stated how data will be collected and protected during the project and either destroyed or reused subsequently; stated what procedures will be implemented in the event of unexpected or incidental findings (in particular, whether the participants have the right to know, or not to know, about any such findings).

The personal data collected were coded, only researchers in charge of the study were able to identify the participant by the name. All personal data were destroyed after 28 days from the end of the data analysis.

AUTHOR CONTRIBUTIONS

All three authors contributed substantially to the above work, with specific tasks. The main author (AO-G): conceptualization, methodology, investigation, validation, writing, original draft. Second author (TP): software; formal analysis, data curation, writing-review, and editing. Third author (FB): validation, supervision, writing-review, and editing.

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ORIGINAL RESEARCH
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Cognitive Restoration in Children Following Exposure to Nature: Evidence From the Attention Network Task and Mobile Eye Tracking

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Exposure to nature improves cognitive performance through a process of cognitive restoration. However, few studies have explored the effect in children, and no studies have explored how eye movements "in the wild" with mobile eye tracking technology contribute to the restoration process. Our results demonstrated that just a 30-min walk in a natural environment was sufficient to produce a faster and more stable pattern of responding on the Attention Network Task, compared with an urban environment. Exposure to the natural environment did not improve executive (directed) attention performance. This pattern of results supports suggestions that children and adults experience unique cognitive benefits from nature. Further, we provide the first evidence of a link between cognitive restoration and the allocation of eye gaze. Participants wearing a mobile eye-tracker exhibited higher fixation rates while walking in the natural environment compared to the urban environment. The data go some way in uncovering the mechanisms sub-serving the restoration effect in children and elaborate how nature may counteract the effects of mental fatigue.

Keywords: Attention Restoration Theory, executive attention, nature walk, intra-individual variance, effort allocation, state regulation

INTRODUCTION

A rapidly expanding evidence base has shown exposure to natural environments (NEs) supports cognitive functioning in adults (e.g., Berman et al., 2008); however, very few studies have explored the effect in children (Stevenson et al., 2018). This is concerning given the potential role nature could play in maintaining optimal cognitive functioning during modern childhoods that are increasingly technological, competitive, and stressful (Song, 2014; Birenbaum et al., 2015).

The framework for understanding the links between NEs and cognitive function is known as Attention Restoration Theory (ART; Kaplan, 1995). According to its advocates, the mental fatigue one experiences throughout the day can be overcome by spending time in NEs. One's capacity to direct attention toward goal-related information, while ignoring irrelevant information, is limited and diminishes with use over time. In contrast to built environments (BEs), NEs contain stimuli that capture attention in an involuntary manner with irrelevant stimuli being ignored more readily and the capacity-limited attentional system being depleted more slowly (Kaplan, 1995). This environmentally induced switch to bottom-up attentional processing is believed to lead to the restoration of abilities that require top-down directed attention. Nature is argued to contain "softly" or intrinsically fascinating stimuli which can be appreciated in a contemplative way without mental effort. That is, thoughts and perceptions are not actively pulled by benign natural stimuli in a way that would otherwise interrupt trains of thought. It has recently been suggested that the reduction in effort required to wilfully control bottom-up attention may foster a beneficial form of internal reflection, or mind-wandering, that supports creative thinking patterns through a simultaneous reduction in the effort required to navigate attention between thoughts and impressions (Williams et al., 2018). Finally, ART also predicts that optimally restorative environments should evoke a sense of *being away* from fatiguing situations; are *extensive* and rich enough to be engaging; and are *compatible* with one's desires (Kaplan, 1995).

The premise that natural stimuli induce a characteristic processing pattern has been explored using lab-based eye-tracking equipment and digital photographs (Berto et al., 2008; Valtchanov and Ellard, 2015). Both studies reported that natural scenes were viewed with fewer fixations than urban scenes, which was interpreted as visual attention being captured in a less-effortful manner. Although the explanations of these differences in visual processing rely heavily on the cognitive mechanisms outlined in ART, to date, there have been no studies linking real-world visual processing of natural environments and subsequent changes in cognitive performance—everything has previously been assessed with photographs in the lab, which likely overlooks the kind of immersive state which ART argues nature brings about. Therefore, the importance of differential sensory processing and sense of engagement, and its association with cognitive performance, remains theoretical.

A recent meta-analysis found that exposure to NEs can lead to improvements in tasks that tap working memory, cognitive flexibility, and attentional control (Stevenson et al., 2018), which are considered the three core executive functions that give rise to higher cognitive operations, such as planning and problem solving (Diamond, 2013). It has been predicted that gains in executive functioning after exposure to a NE occur due to the restoration of directed attention, a common resource tapped during performance of the tasks used to assess these abilities (Kaplan and Berman, 2010). The constructs of directed attention and executive attention both describe the ability to focus attention while simultaneously ignoring distraction and are considered to be synonymous (Diamond, 2013). In adults, this ability is selectively improved after exposure to NEs when assessed using a task that separates executive attention from other processes, namely, the Attention Network Task (ANT) (e.g., Berman et al., 2008). The ANT produces a performance indicator (executive score) that most closely captures the directed attention construct described in ART (Ohly et al., 2016); indicators of non-executive attention performance (orienting and alerting scores); and general or temporal indicators of performance, such as speed (mean reaction time) and stability (standard error of reaction time). Therefore, utilizing the ANT in studies exploring restorative environments may extend current understandings of the restoration effect, as the mechanisms behind the effect, particularly in children, appear to be obscured.

Two large epidemiological studies involving the ANT suggested children between the ages of four and 10 years may benefit from NEs in ways distinct from adults. Dadvand et al. (2015, 2017) found that the amount of greenspace around the homes and schools of children was related to a reduction in intra-individual variability in reaction time (IIVrt), indexed using standard error of reaction time. Dadvand et al. (2017) study also found an association between greenspace and a reduction in IIVrt and omission errors on Conner's Kiddies Continuous Performance Test. Further investigations in the same population revealed significant increases in gray matter volume in bilateral prefrontal areas, and increases in white matter volume in right prefrontal areas related to exposure to greenspace (Dadvand et al., 2018). This is a particularly important finding for ART given that stimulus-based (i.e., bottom-up) and voluntary (i.e., top-down) attention networks converge in lateral prefrontal areas (Asplund et al., 2010), and white matter maturation is associated with reduced IIVrt (Tamnes et al., 2012). These studies suggest that, for children, cognitive resources regulating temporal aspects of performance, such as state regulation (Wiersema et al., 2005), may be more sensitive to NEs than a more specific executive resource. This is supported by the only two randomized controlled trials to investigate the effect in typically developing children. Jenkin et al. (2017) found children were worse at delaying gratification of a future reward after exposure to digital BEs compared to natural environments, while selective attention, measured by the Stroop Task, remained unchanged. Schutte et al. (2017) found that children responded faster in the Continuous Performance Task and Go/NoGo Task after walking in a natural environment but did not show improvements in spatial working memory and response inhibition. While it appears children and adults may receive separable restorative benefits from exposure to natural environments, the exact mechanisms driving the effect remain obscured without additional measures that go beyond behavioral performance, like mobile eye tracking.

The Present Study

The first aim of the present study was to investigate whether exposure to a NE improves children's performance on the ANT, owing to a real-time or immediate restoration mechanism. We used a randomized crossover design to test whether children show directed attention improvements related to restoration effects. Additionally, we were interested in whether the previously reported long-term effects on IIVrt can be replicated and attributed to a restorative process, using a standard ART protocol, where mental fatigue is induced prior to environmental exposure. The final aim was to investigate whether visual processing differed between the two environments, as indexed by eye movement recordings using mobile eye tracking technology in the real world (Tobii Pro II eye-tracking classes).

We predicted that children's performance on the ANT would be improved after a short walk in a natural environment.

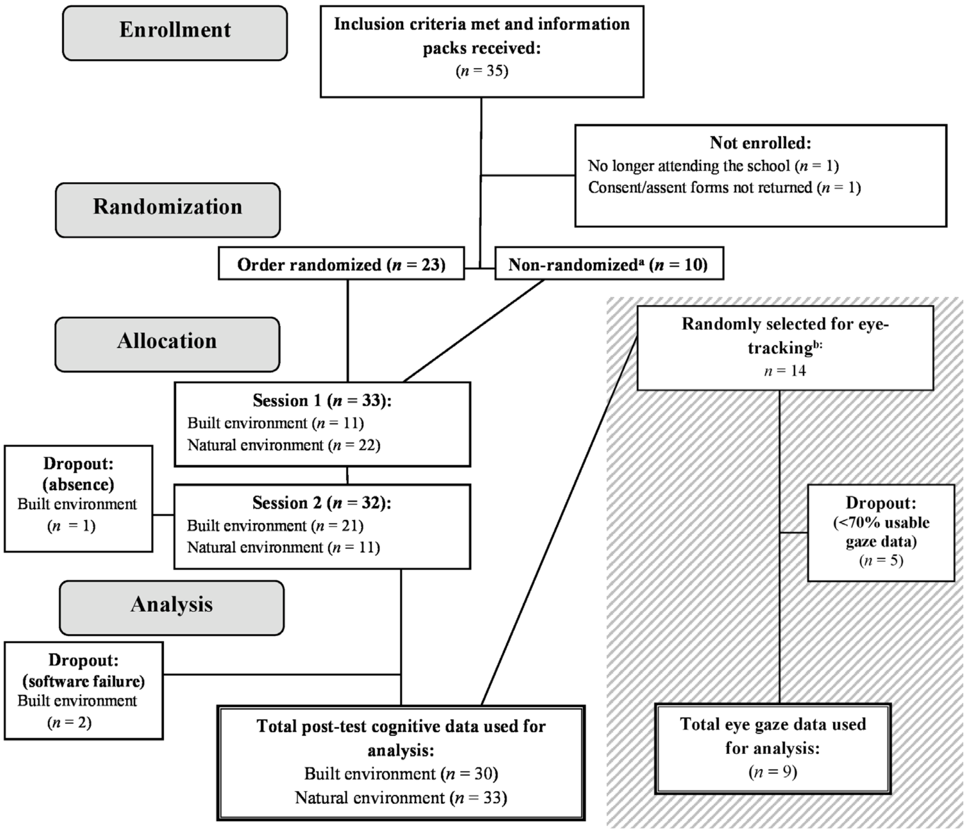

FIGURE 1 | CONSORT flow diagram. A CONSORT-inspired flowchart depicting participant numbers through phases of the study from recruitment to data analysis, including participant dropout points. The details of the eye-tracking data collection are presented in the gray box. [a]Computerized randomization of environment order was only possible for 23 out of 33 participants (69.7%) due to logistic restraints caused by the participants' academic schedule. [b]Randomization of environment order for eye-tracking data collection was not possible for the same reason. All eye-tracking data were collected first in the natural environment, followed by the built environment (BE).

However, contrary to past studies with adult participants, we predicted improvement to be indexed by temporal performance indicators (reaction time, standard error of reaction time), rather than attention-specific performance indicators (executive score) We suggest such a pattern of results would reflect the restoration of a broader, regulatory, or energetic resource, rather than the restoration of directed attention, which has been attributed to performance gains in adults (Berman et al., 2008). Further, we predicted children would view the natural environment with fewer and longer fixations than the BE, reflecting the engagement of an attentional system that requires less top-down control. Finally, we predicted a significant association between cognitive performance and fixation measures, suggesting that gains in cognitive performance are to some extent dependant on the visual processing of NEs.

MATERIALS AND METHODS

Study Design

We conducted a semi-randomized crossover trial using environment type as a within-subjects treatment variable with two levels (i.e., natural and built). For the first 23 participants (69.7%), the order of environment was randomized; however, this was not possible for the remaining participants due to restraints of their school schedules.

Participants

Thirty-three children (m = 12.03 years; 60.6% female) were recruited from an independent school in Naestved, Denmark, from which a teacher had responded to a call for participants for a similar study. **Figure 1** illustrates the flow of participants from recruitment to data analysis. Participants were recruited across three grade levels with the age of participants ranging from 10 to 14 years. The study was introduced to the school during a parent assembly. The information presented was carefully worded to not disclose hypotheses or any details that may influence behavior during the study. The research was presented as a study of walking, while details that would reveal the expectations from the environment and our hypotheses were withheld. Discussions and information letters included phrases such as "walking in two different environments" to avoid using language that could be construed as nature-positive. Interested parents were given an information pack that included written consent and assent forms. Only participants whose parents had signed consent forms after discussing participation took part in the study. In line with national and institutional standards, there was no formal ethical approval required for this type of study.

Most participants were somewhat familiar with both environments used in the study. Participants with a current diagnosis of any behavioral or cognitive disorder were excluded. There were no further criteria for exclusion. Cognitive data from two participants could not be used due to computer failures, and one participant did not complete the entire protocol. Fourteen participants (*m* = 12.43 years; 71.4% female) were randomly selected from the original sample to take part in the data collection for eye-tracking measures.

Measures and Equipment

The Attention Network Task (ANT)

Participants performed a child-friendly version of the ANT which measures three distinct attention systems (Rueda et al., 2004). The task contained three blocks of 48 trials, preceded by a 12-trial practice block with feedback on performance. Each block lasts around 5 min with a rest period offered between blocks. During each trial, participants responded to the direction a centrally presented cartoon fish was facing. For trials that measure alerting ability, a cue is presented to inform the participants a target will appear. Performance on these trials is contrasted with trials that do not present a cue. The alerting cue facilitates performance, which is reflected in shorter reaction times during cued trials. For the trials that measure orienting ability, a spatial cue is presented to show the place in which the target stimulus will appear. Performance on these trials is contrasted with trials where a neutral cue is presented. The spatial cue facilitates performance, resulting in shorter reaction times. The trials that measure executive attention ability are similar to a common Flanker Task (Mullane et al., 2009). During these trials, the target fish is flanked by four other fish pointing in congruent or incongruent directions. Trials with incongruent flanker stimuli are contrasted with trials with congruent flanker stimuli. Incongruent flankers are associated with slower reaction times, reflecting the need to overcome a higher level of distraction. Four main outcome variables derived from behavioral ANT data. The executive attention score (EXE) was included as an index of directed attention ability; standard error of reaction time on all correct trials (SERT); mean reaction time on all correct trials (mRT); and total accuracy (ACC) were included as temporal or general performance indicators.

The Perceived Restorativeness Scale for Children (PRS-C II)

The PRS-C II is an age-adjusted version of the Perceived Restoration Scale that was created to obtain subjective ratings of restorative environmental components (Bagot et al., 2007), as described in ART (Kaplan, 1995). The scale contains 15 likert-style items that produce an overall perceived restorativeness score derived from sub-scales including fascination, compatibility, extent, being away – psychologically (e.g., novelty), and being away – physically (e.g., escape). The original scale was developed with reference to environments specific to children, such as school (Bagot, 2004); however, we adjusted the wording in order to relate the questions to the two environments used in our study. We replaced the original words "school ground" (Bagot et al., 2007) with "forest" (*Danish:* "*skov*") and "streets" (*Danish:* "*gader*") to capture features of the two environments. For example, "*The things I like to do can be done in the forest*" and "*The things I like to do can be done in the streets*." The two versions of the PRS-C II were translated to Danish and were found to have similar levels of reliability (Cronbach's alpha: "forest" version, $\alpha = 0.87$; "streets" version, $\alpha = 0.81$) for total perceived restorativeness as other translated versions (e.g., $\alpha = 0.84$, Collado and Corraliza, 2017). Each participant completed one PRS-C II questionnaire for each environment. The total perceived restorativeness scores were used during analysis.

Tobii Pro 2 Mobile Eye-Tracking Glasses

Eye-tracking data was collected at a sampling rate of 50 Hz using Tobii Pro 2 glasses and processed using Tobii Pro Lab software. The glasses record first-person video through a wide-angle lens centered between the eyes (the scene camera). The coordinate system for eye-gaze localization relates the pupil-center corneal-reflection-vector to positions from the scene camera, using an infra-red light source (Holmqvist et al., 2011). Eye movement types were categorized using the Velocity-Threshold Identification Fixation Filter. This filter uses velocity threshold algorithm where raw gaze data under a certain velocity level are deemed to be fixations, while gaze data over a certain velocity level are deemed to be saccades. A threshold of 30 degrees per second was used for classifying fixations.

Environmental Exposures

Figures 2, **3** present the two environments used, which were located within the local municipality, and familiar to most participants. For cognitive data collection, participants walked for 30 min on looped routes that were matched as closely as possible for pedestrian traffic, length, and gradient. Despite best attempts to match urban and natural walking environments, the urban walk contained a short section (i.e., 1–2 min) where noise was generated by a construction site and contained notably more traffic in the first and last 3–4 min. Natural features were present on the urban route, including planted trees and gardens, although these were sparsely distributed. Similarly, man-made features were sparsely distributed on the natural route, including fencing, sheds, vehicles, houses, benches, and signage. The natural walking environment was a rural area called Myrup. The route consisted of rolling grass fields, walking tracks through young pine trees and rocks, farmland, and forest containing mostly beech and birch. The route formed a complete loop with no backtracking. The built walking environment was a quiet neighborhood area adjacent to the main town area of Naestved. The route initially passed shops to lead out of the town area and then circumnavigated a cemetery with high stone walls, passing a mostly residential area with a primary school. The loop contained around 8 min of backtracking. The walking routes for eye-tracking data collection consisted of following the original routes for 5 min, before backtracking for 5 min to the beginning.

FIGURE 2 | Route map and photographs of the built environment exposure walk. Aerial map of Næstved, Denmark, where the route for the built environment exposure walk was selected (marked in red). A youth centre was the location of the cognitive testing area and the start/end point for the route. The route map was created using MapMyRun (http://www.mapmyrun.com).

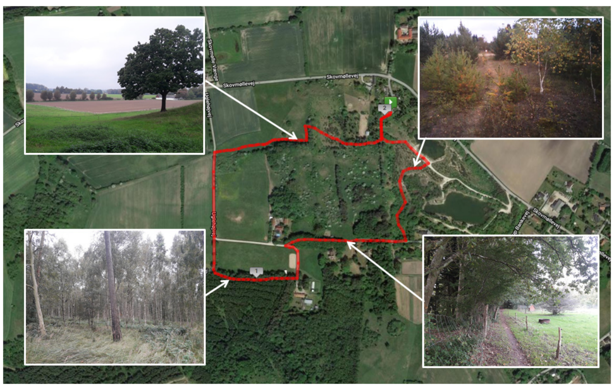

FIGURE 3 | Route map and photographs of the natural environment exposure walk. Aerial map of Myrup, Denmark, where the route for the natural environment exposure walk was selected (marked in red). A rural property located in Myrup was the location of the cognitive testing area and the start/end point for the natural environment route. The route map was created using MapMyRun (http://www.mapmyrun.com).

Procedure

Data was collected over two sessions, conducted on Mondays and Thursdays of two consecutive weeks. Participants were randomly assigned to a day, containing one of two permutations of environmental exposure. Those assigned to the Monday sessions received the exposure order *natural, built;* those assigned to the Thursday sessions received the exposure order *built, natural.* Time of testing was controlled by ensuring each participant was tested at roughly the same time (∼08:30; ∼10:30; or ∼12:30) during each session, and sessions were canceled due to any amount of rain.

In groups of four-five, participants sat at their own work station in a quite testing area, where the walks began and ended. They first performed the Digit Span Forward and Digit Span Backward Tasks, which lasted 12–15 min. This task was chosen to induce cognitive fatigue as it has been shown to be among the most sensitive measures to the restoration effect and therefore likely depletes relevant cognitive resources. To ensure participants allocated sufficient effort during these tasks there was a competition and prize for best performance, which participants were informed of prior to completion. Participants then performed the ANT (Fan et al., 2002) to obtain baseline measures of cognitive performance in their fatigued state. The ANT took around 15 min. Immediately after, participants walked in groups of four or five for 30 min along a predefined route in either a natural or BE. During the walk, there were 2 min periods where participants were encouraged to not communicate, to relax, and experience their surroundings. These periods were broken by periods where the experimenter asked the participants to comment on what they have seen, heard, smelt, and felt whilst walking. This activity was included to help the participants feel comfortable and ensure there was a degree of mindful interaction between the participants and their environment. In this way, the ratio between talking and silent periods was not strictly standardized and was applied at the discretion of the experimenter based on the atmosphere and engagement of the group. There were between six and eight talking periods during the walks, depending on the number of impressions offered by the group. Upon returning from the walk, participants sat at their workstations and performed the ANT once more to give post-treatment measures of cognitive performance. Finally, participants completed the version of the Perceived Restorativeness Scale for Children that corresponded to the environment in which they had walked.

Eye-tracking data were collected during two additional sessions in which the order could not be randomized. Therefore, all participants walked in the natural environment first for the eye-tracking data collection. After calibration procedures, 14 randomly selected participants walked one at a time with the experimenter wearing Tobii Pro II glasses following a 10-min segment of the routes used during cognitive data collection. Participants were instructed to try to relax and experience the environment as they normally would. All participants walked the same segment of the original routes with only a researcher to accompany them. Data collected for the first 2 min of the eye-tracking walk were discarded to allow for habituation of wearing the glasses. Data epochs were segmented from 2-min into the recording until a particular feature on the route was present. This resulted in slight variation in recording lengths due to variation in the speed at which participants walked. Therefore, fixation rate per minute was used as an outcome measure to normalize for this. We also took average length of fixation as an additional eye tracking measure.

Statistical Analysis

The effect of environment type on cognitive performance was analyzed using an "intention-to-treat" approach. Initially, the data was visually inspected to remove outlier responses that were under 200 ms (<0.003%). Pre- and post-test averages from the four measures of cognitive performance (EXE, ACC, mRT, SERT) were then calculated for all participants across all three blocks of the ANT.

Mobile eye-tracking in outdoor environments is associated with challenges that lead to reduced pupil identification and therefore lost signal. For example, regular natural lighting causes constriction of the pupil, and high levels can cause squinting (Evans et al., 2012). To ensure the most reliable eye-tracking data were analyzed, we excluded participants with gaze sample rates lower than 70%—that is, for all remaining participants no more than 30% of raw sample data was lost for the entire recording period.

Paired samples *t*-tests were conducted to compare perceived restorativeness scores, total number of fixations, and average duration of fixations across the two environments. A series of linear mixed models (LMM) were used to analyse how post-test cognitive performance varied as a function of environment, while controlling for pre-test (baseline) scores. LMMs were used to account for the dependence of data points and the occurrence of missing data, which was done through restricted maximum likelihood estimations. The initial models fitted to the cognitive data included environment (i.e., natural, built) as a fixed factor, subject as a random factor, and pre-test (baseline) scores as a covariate. Follow-up analyses were conducted in a stepwise manner to reduce residual variance from other variables collected during the study. These included age, gender, order of environment; restoration tendency (PRS-C nature minus PRS-C built), number of fixations per minute, and average fixation length. Effect sizes (Cohen's *d*) were calculated for significant main effects.

Power Analysis

Power studies require knowledge about the expected effect size as well as of the variation of the outcome variable. These figures were difficult to obtain as there were no previous studies with children reporting the effect of short-term exposure to natural environments on ANT performance at the time of this study's conception. Until Dadvand et al. (2015) the environmental effect was assumed to be found using the executive attention score. Therefore, we conducted a tentative power analysis based on adult literature (e.g., Berman et al., 2008) where we estimated a decrease of 20 ms in RT in executive score for the natural environment and no decrease for the BE. Estimating variance is more difficult as it varies greatly between studies and populations. Nevertheless, a standard deviation of around 20 was selected based on available evidence of children's performance on the ANT (e.g., Adólfsdóttir et al., 2008). With these values, 40 children are required to get a power of 90% (when the test is carried out with significance level 5%).

RESULTS

Participant Characteristics and Eye-Tracking

Thirty-two participants from the initial 33 recruited completed the experimental protocols in both environments, while one participant did not attend an assigned session due to sickness. Participants with ANT accuracy scores that were more than two and a half standard deviations below the mean were deemed to have unreliable task performance and their data was excluded. Based on this criterion, post-test data from a single session were excluded for two participants. One pre-test score from another participant was removed due to computer failure. These exclusions resulted in total of 33 and 30 participants included in the analyses for natural and BEs, respectively. The differences in age and gender between the two conditions were negligible (see **Table 1**). As predicted, the participants perceived the natural environment as being more restorative than the BE, $t(29) = 2.56$, $p = 0.016$.

TABLE 1 | Participant details and eye-tracking data.

Participant characteristics	Natural environment	Built Environment	*p*-value	ES
ANT data				
Sample size*	33	30		
Age	12.03 (1.21)	12.00 (1.23)		
Gender (male/female)	13/20	12/18		
Perceived restorativeness Scale	44.80 (8.69)	39.57 (10.84)	**0.016**	0.180
Eye-tracking data				
Sample size†	9	9		
Minutes analyzed	5.72 (0.74)	5.78 (0.86)	0.855	
Fixations per minute	157.97 (11.47)	145.01 (10.70)	**0.033**	1.168
Fixation duration	181.78 (26.22)	184.44 (32.93)	0.807	

*ES: effect size (Cohen's d). *Data from the built environment sessions of three participants were excluded due to non-completion (n = 1) and computer software failure (n = 2). Paired samples t-test on Perceived Restorativeness Scale data conducted with a total sample size of n = 30. †Data collected from a randomly selected sub-sample [original subsample n = 14; five participants excluded from analysis due to unreliable eye-tracking data (gaze sample rates under 70%)]. Bold type indicates a significant effect (p < 0.05).*

From the 14 participants randomly selected for eye-tracking data collection, five were excluded due to poor quality data (gaze sample rate under 70%). Checks were performed to ensure the group used for eye-tracking data analysis was representative of the initial participants recruited. The participants whose data was included in the analysis did not differ from the other participants in terms of age ($p = 0.094$), gender ($p = 0.283$), or PRS scores for the natural ($p = 0.163$) or BEs ($p = 0.982$). Moreover, the total number of minutes used for eye-tracking analysis did not differ between the two environments ($p = 0.855$). Participants made a greater number of fixations per minute while walking in the natural environment than in the BE, $t(8) = 2.567$, $p = 0.033$; however, there was no difference in the average duration of fixations between the two environments, $t(8) = -0.253$, $p = 0.801$.

The Effect of Environment on Cognitive Performance

The main effect of environment was of primary interest during the analysis. **Figure 4** displays the post-walk means and standard deviations for the four outcome measures of interest, adjusted for baseline performance. The initial base model used for analysis included baseline score as covariate

TABLE 2 | Means and standard errors for Attention Network Task (ANT) outcome measures (adjusted for baseline performance).

ANT outcome measures	Natural environment	Built environment	Main effect *P*	(Envi) ES
Executive attention score (EXE)	58.69 (7.46)	68.73 (7.96)	0.361	
Accuracy (ACC)	139.50 (0.56)	139.12 (0.60)	0.647	
Mean reaction time (mRT)	604.73 (9.45)	625.12 (9.83)	**0.024**	−0.383
Standard error of reaction time (SERT)	14.70 (0.50)	16.08 (0.53)	**0.013**	−0.486

ES = effect size (Cohen's d). Bold type indicates a significant effect (p < 0.05).

TABLE 3 | Linear mixed models exploring the effect of environment on Attention Network Performance in typically developing children.

	Model 1	
	β (95% CI)	*p*-value
EXE		
Envi	−10.034 (−31.856, 11.788)	0.361
Baseline	0.424 (0.126, 0.722)	**0.006**
Intercept	42.437 (17.839, 67.035)	**0.001**
AIC	632.984	
AIC Model 0	640.447	
ACC		
Envi	0.380 (−1.271, 2.032)	0.647
Baseline	0.727 (0.569, 0.884)	**<0.001**
Intercept	64.390 (34.608, 94.172)	**<0.001**
AIC	322.864	
AIC Model 0	324.525	
mRT		
Envi	−20.387 (−37.911, −2.863)	**0.024**
Baseline	0.772 (0.610, 0.934)	**<0.001**
Intercept	183.144 (85.333, 280.955)	**<0.001**
AIC	648.357	
AIC Model 0	659.758	
SERT		
Envi	−1.387 (−2.464, −0.310)	**0.013**
Baseline	0.660 (0.470, 0.849)	**<0.001**
Intercept	7.029 (4.135, 9.923)	**<0.001**
AIC	301.381	
AIC Model 0	308.211	

Linear mixed models predicting executive attention (EXE), accuracy (ACC), mean reaction time (mRT), and stability of performance (SERT) on the Attention Network Task. The base model includes baseline as a covariate, subject as random factor, and environment as the fixed effect of primary interest. Follow-up stepwise modeling revealed no significant contribution of additional factors and did not improve the base models. AIC, Akaike information criteria; was used to aid model selection. AIC of Model 1 was compared with AIC of Model 0, which contained the parameters of Model 1 minus the environment factor. Bold type indicates a significant effect (p < 0.05).

and subject as a random factor. As shown in **Tables 2**, **3**, participants did not show improvements in executive attention or accuracy when exposed to the natural environment. However, exposure to the natural environment was associated with significantly faster reaction times on correct responses, $\beta = -20.387$, $p = 0.024$, and improved stability of performance, $\beta = -1.387$, $p = 0.013$. For follow-up analyses, we included additional factors in order to reduce variance in the base model. In addition to baseline performance, we explored the influence of age, gender, order of environment, and restorativeness tendency score, plus fixations per minute and average fixation length, in a step-wise manner. While the effect of baseline performance was significant in all base models, the additional factors applied in follow-up analyses did not significantly influence cognitive performance, across all measures.

DISCUSSION

We investigated the restorative effect of NEs on children's cognitive performance in a semi-randomized crossover trial. Participants exhibited faster and more stable responding while performing the ANT after 30-min walks in a NE compared to a BE, when controlling for baseline performance. We found no evidence of improved executive attention or overall accuracy. Participants rated the NE more restorative than the BE; however, ratings did not influence cognitive performance. Performance was not influenced by age, gender, or order of environment. A randomly selected sub-sample, who wore mobile eye-trackers that recorded aspects of visual processing while walking in both environments, exhibited a higher fixation rate within the NE than the BE. No differences in average fixation duration were found. While the effect size for fixations per minute was large ($d = 1.1$), interpretations remain tentative and should be met with caution given the relatively small sample size ($n = 9$). When eye-tracking outcomes were included in the linear mixed models, they did not predict cognitive performance.

Dadvand et al. (2015, 2017) showed that long-term exposure to greenspace positively influences the development of cortical regions and cognitive processes associated with performance stability in children. We support these findings by confirming that an acute exposure to a NE can also improve performance stability on the ANT in children. However, our results also showed that reaction time can also be positively influenced, which has not been previously reported.

Kaplan and Berman (2010), argued that directed attention is a cognitive resource recruited by both executive and self-regulatory processes. Self-regulatory processes, including effort allocation and the ability to maintain appropriate states of arousal, are often entwined within models of executive functioning (Diamond, 2013). Therefore, the finding that natural environments can improve the ability to control responding to meet the demands of a repetitive mundane task, such as the ANT, may not be surprising. A reduction of IIVrt may reflect an improvement in effort allocation or regulating arousal states (Wiersema et al., 2005). We recommend that future studies of restoration using multi-trial tasks report IIVrt,

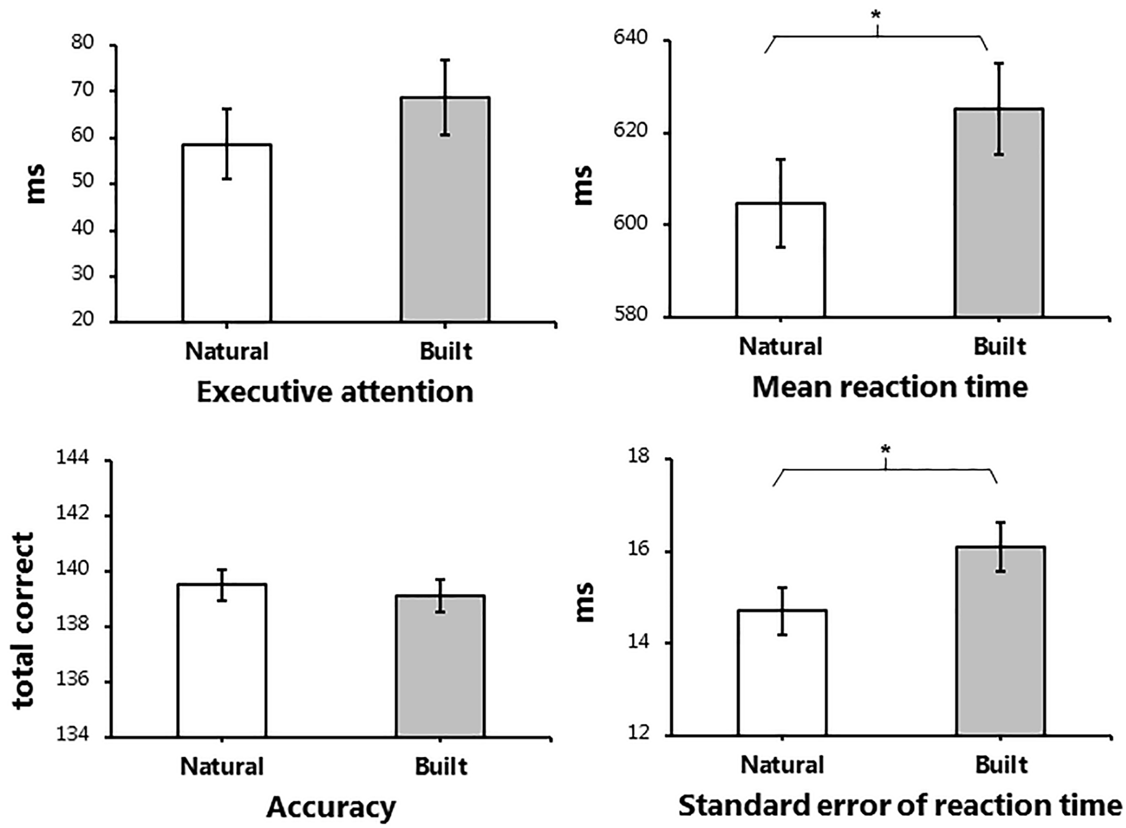

FIGURE 4 | Adjusted post-walk data for performance of the Attention Network Task. Adjusted means and standard errors of the initial base model applied during linear mixed model analysis for the four outcome measures of the Attention Network Task. The post-test data displayed in the figure were adjusted using baseline data as a covariate. Subject was included in the base model as a random factor. ms: milliseconds. Significant main effects of environment are marked, *$p < 0.05$.

classic executive measures, and additional measures to explore mechanisms underlying behavioral performance, such as eye-tracking.

The large difference in fixation rates found between the environments goes against previous reports using screen-based eye-tracking. However, interpretation of this discrepancy remains ambiguous. As Berto et al. (2008), p. 186 referred to fixations as a measure of "periods of focused attention," they concluded that fewer fixations must reflect a reduction in cognitive effort when viewing natural scenes. However, if cognitive effort refers to the ease in which attention is successfully shifted between one visual target to another, a greater number of shifts, or fixations, would reflect an environment that was more effortless to process. Fixations are traditionally known as the times at which visual information is acquired and the next target is selected (Rucci and Poletti, 2015). This would predict a greater number of fixations as a proxy for better overall apprehension of a scene. Hence, nature evokes intrinsic fascination and a desire to explore the scene while acquiring visual information, but in a way that is not taxing to the cognitive system. This may be considered intrinsic fascination at an environmental level, while intrinsic fascination at a stimulus level would predict longer durations while fixating on natural stimuli, as shown by Valtchanov and Ellard (2015). Differences in eye-tracking results may also reflect the mode of environmental exposure, where our participants experienced full sensory exposure, rather than purely visual exposures, as used in previous studies. We hope the investigation will encourage a move away from the lab and static scenes toward more immersive ethnographic research.

Limitations

A power analysis conducted during the planning phase of the study suggested 40 participants would be required to achieve an acceptable level of power for the analysis of cognitive data. Unfortunately, due to time and logistical restraints associated with the participants' academic schedules, we were required to cease recruitment prior to achieving this number. However, it is worth remembering that our initial power analysis was conducted using a more conservative target power of 90%. A more conventional target of 80% power would have resulted in a lower required sample size. Such an estimate may now be appropriate using the data derived from this current study involving children.

Due to the uniqueness of the sub-study involving eye-tracking, it was not possible to perform a power analysis to estimate the required sample size, even to a tentative degree. While we warn against drawing strong conclusions based on this data set alone, we encourage researchers to pursue larger studies to explore the relationships between visual processing in NEs, cognitive performance gains, and a restoration mechanism. Indeed, the eye-tracking data presented in this article may provide information necessary to conduct power estimates for larger studies in the future.

The current study would have also benefited from a more thorough analysis of the participants' experiences during the walks to better describe the conditions necessary for restoration-related cognitive gains in children. Collado and Staats (2016) highlighted the need to explore the uniqueness of children's experiences with their environment when considering the restoration effect in this age group. Among their considerations, they noted that children differ from adults in terms of their receptivity toward changing social contexts. One challenge of the present study was to maintain a positive social atmosphere during the walks that would promote, rather than impede, the restoration process. The peer groups in which the participants walked were identical across environments to control for social context. However, the groups were chosen at random so that participants were not necessarily placed with peers to whom they were close. To investigate the purported moderating effect that social contexts have on restorative states in children (Collado and Staats, 2016), future studies should include quantitative measures of group cohesion or relationship proximity between peers within walking groups.

Further, according to Collado and Staats (2016), a thorough audit of children's restorative experiences should also include measures of place attachment. In the present study, most participants were familiar with both environments. However, this observation was based on informal rapport-building conversations between the participants and the experimenter, rather than being quantified in a way that could be used during analysis. It is possible to speculate that familiarity with the area in which the nature walk took place, or heightened attachment, may have enhanced the restorative value of the environment and therefore inflated the effects on cognitive performance. Whether positive place attachments and positive social contexts are necessary conditions in which children can achieve cognitive restoration during exposure to a natural environment remains unclear. However, such knowledge may have considerable bearing upon how future studies with child participants are conducted.

CONCLUSION

Based on our pattern of results, which supports previous studies (e.g., Dadvand et al., 2015), we continue to speculate that the cognitive systems of children benefit in a different way to adults in response to nature exposure. Specifically, restorative environments may be more sensitive to cognitive processes related to temporal indicators of cognitive performance, (e.g., standard error of reaction time), rather than those specifically related to directed attention (e.g., executive score of the ANT). Future accounts of ART may need to be revised to accommodate this apparent difference between adults and children, should this distinction persist under future investigations. Ideally, future studies would compare children and adults within the same study. The diverging results between age groups highlight limitations of current descriptions of the restoration effect. Pairing cognitive outcome measures with additional measures that quantify the experience in NEs, such as eye-tracking, is the next step toward understanding how cognitive systems benefit from nature. Such knowledge would provide crucial information for parents and educators seeking opportunities for respite in the age of increased reliance on digital technology for child entertainment and learning.

ETHICS STATEMENT

By law in Denmark, only biomedical studies where tissue is collected or those involving treatments with inherent risk to patients/participants must have their ethics reviewed by a Regional Ethics Board; all other research projects are exempt from applying for formal ethical approval.

AUTHOR CONTRIBUTIONS

All authors developed the study concept design and approved the final version for submission. Data collection was performed by MS and research assistants. Data analysis were performed by MS and RD. Interpretation of results was carried out by all authors. MS, PB, and TS drafted the manuscript.

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Children's Cortisol and Cell-Free DNA Trajectories in Relation to Sedentary Behavior and Physical Activity in School: A Pilot Study

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The worldwide prevalence of mental disorders in children and adolescents increased constantly. Additionally, the recommended amount of physical activity (PA) is not achieved by this age group. These circumstances are associated with negative impacts on their health status in later life and can lead to public health issues. The exposure to natural green environments (NGE) seems to be beneficial for human health. The compulsory school system offers great opportunities to reach every child with suitable health-related contents and interventions at an early stage. The concept of Education Outside the Classroom (EOtC) uses NGE and sets focus on PA. Therefore, EOtC might be a beneficial educational intervention to promote students health. The association between biological stress markers and sedentary behavior (SB) plus PA is insufficiently evaluated in school settings. This exploratory study aims to evaluate the association between students' cortisol, plus circulating cell-free deoxyribonucleic acid (cfDNA) levels, and their SB, light PA (LPA), and moderate-to-vigorous PA (MVPA). We assessed data from an EOtC program (intervention group [IG], $n = 37$; control group [CG], $n = 11$) in three seasons (fall/spring/summer) in outdoor lessons (IG) in a NGE and normal indoor lessons (CG). SB and PA were evaluated by accelerometry, and cortisol and cfDNA levels by saliva samples. Fitted Bayesian hierarchical linear models evaluated the association between cortisol and cfDNA, and compositional SB/LPA/MVPA. A steady decline of cortisol in the IG is associated with relatively high levels of LPA (posterior mean = −0.728; credible interval [CRI 95%]: −1.268; −0.190). SB and MVPA tended to exhibit a similar effect in the CG. A high amount of cfDNA is positively associated with a relatively high amount of SB in the IG (posterior mean, 1.285; CRI: 0.390; 2.191), the same association is likely for LPA and MVPA in both groups. To conclude, LPA seems to support a healthy cortisol decrease in children during outdoor lessons in NGEs. Associations between cfDNA and SB/PA need to be evaluated in further research. This study facilitates the formulation of straightforward and directed hypotheses for further research with a focus on the potential health promotion of EOtC.

Keywords: cortisol, cfDNA, physical activity, health, outdoor environment, Bayesian inference

INTRODUCTION

The upsurge in the worldwide prevalence of overweight and obesity in children is anticipated to reach 9.1% in 2020 (1), a high proportion of children do not reach the recommended levels of physical activity (PA) (2, 3), and suffer from mental disorders (4). Chronic stressful events could exert adverse impacts on brain development and result in major mental health-related problems in later life (5, 6). These circumstances require a need for action to improve children and adolescents health perspectives. Successful interventions should therefore consider that (1) PA and exercise during childhood is associated with the development of active lifestyles in later life, improved cognitive functions (7, 8) and, thus, with positive effects on health and prevention of common diseases (9), (2) the exposure to natural green environments (NGE) can have beneficial health effects [see e.g., (10, 11)], and that (3) children spend a substantial share of their waking hours in school. Therefore, the compulsory school system in western countries offers excellent opportunities to reach every child and adolescent with specific interventions focusing on PA in NGE to improve children and adolescents health perspectives.

The present paper aims to address these topics by investigating the relation between biological stress responses and physical activity in students taught in two different school settings: an indoor setting and an outdoor setting in a NGE. Here, we extend our original investigation (12) by increasing our set of dependent variables and introducing circulating cell-free deoxyribonucleic acid (cfDNA) as an innovative biological marker, sedentary behavior (SB) and light physical activity (LPA) as more differentiated measures of physical activity and by applying advanced statistical models to better describe relations between our measures.

Both cortisol and cfDNA are important biomarkers in relation to stress, SB and PA. Thus, the comparison of both cortisol and cfDNA in relation to students' relative levels of SB and PA is a promising approach to investigate students' biological stress response in different school settings. Important findings on cortisol and cfDNA in relation to physical and psychosocial stressful situations are therefore outlined.

Recent studies have focused on exploring the construct of "stress" and its potential negative association with health (13). In fact, an individual's physiological and psychological response, assessed by different stress biomarkers or questionnaire items, could be correlated with several positively, as well as negatively, connoted stimuli. Koolhaas et al. (13) argued that the term "stress" should be restricted to situations of uncontrollability or unpredictability of stimuli which however, must be restricted to "psychological stress" and is not true for so called "physical stress" (14, 15), which can be defined as a loss of homeostasis induced by physical not psychological conditions. Examples of such uncontrollable situations in school are examinations, testimonials, increased mental loads or prolonged social pressure (16, 17). Such stressors can lead to an interruption of the regular circadian cortisol rhythm. The relevance of a normal diurnal cortisol rhythm with high levels of cortisol in the morning and a steady decline until evening has been widely investigated (18–20). Furthermore, several external stimuli could be involved in the disturbance of a normal diurnal cortisol rhythm, for instance, light pollution during nighttime, or continuous changes in waking hour schedules. Moreover, a dysfunctionality in the hypothalamic pituitary adrenocortical (HPA) axis as one primary biological stress system plays a crucial role. In a recent systematic literature review and meta-analysis, Adam et al. (21) reported that a chronic abnormal flat diurnal cortisol rhythm correlated with poor mental and physical health symptoms for various populations. Other experimental studies (22, 23) evaluated the association between cortisol levels and PA, with a particular focus on different PA intensities, as well as the diurnal cortisol rhythm. These studies revealed that high PA intensities ranging from 60 to 80% of the maximal oxygen uptake (VO2 max) (22) or 80% VO2 max (23) for, at least, 30 min resulted in statistically significant higher cortisol levels compared with resting control situations. Interestingly, participants' cortisol levels decreased, although not statistically significant, not only in the resting control groups (CG) but also during low PA intensities of 40% VO2 max. These studies illustrate the potential impact of PA on cortisol levels.

Besides the well-established but also critically discussed stress marker cortisol (24), the circulating cfDNA has garnered more importance as a potential physiological stress marker. Different mechanisms can result in the release of the cfDNA into the human plasma. While an increase in cfDNA levels because of classic cell-death mechanisms would take several hours, or even days, other more rapid mechanisms are related to exercise. Based on plasma samples, the cfDNA is a well-established indicator of the activation of the innate immunity. Various studies have revealed that the innate immunity could be activated by both psychologically (25, 26) and physiologically (27–32) stressful situations. In particular, the cfDNA has been proven to be highly sensitive to physical exercise as a stressor [see (27) for review]. Reportedly, the cfDNA increased with moderate PA below the level of the aerobic–anaerobic transition (29, 33). A recent study (30) reported that cortisol and plasma cfDNA levels positively correlated and both increased in participants under physiological and psychosocial stressful situations. Regarding psychological stress little is known about the reactivity of cfDNA concentrations. To date, only one study has reported that lowering psychological stress in women treated for infertility reduces the plasma cfDNA concentration, a notion that is principally in line with the concept of a stress-associated, sensitive proinflamatory marker (34). Furthermore, current research suggests that major depressive symptoms are associated with elevated levels of cfDNA (35, 36). Cianga et al. (37) studied cfDNA in saliva of immunosuppressed patients. The results indicate that the most important source of DNA in saliva samples are leukocytes that travel from the blood to the oral cavity, where they play an important role in protection against pathogens. The specific cells and tissues, which are involved in psychological induced cfDNA elevation, are still unknown. However, the effect of stress hormones on leukocyte profiles is well-documented in biomedical studies of mammals. This includes glucocorticoid-induced alterations in cell trafficking, or redistribution from blood to other body compartments [reviewed in Davis et al. (38)]. This furthermore indicates an indirect link between cortisol and cfDNA. Higher cortisol values were associated with a greater number of neutrophils (38). In response to infection, tissue injury or exercise, neutrophil glucocorticoids can produce extracellular traps, which are likely to contribute to the pool of cfDNA (39). Most research on the cfDNA is restricted to plasma samples and controlled laboratory settings. However, a study has reported that the cfDNA in the saliva and serum possess a similar half-life time and both follow a first-order clearance model (40). Furthermore, in both body fluids, the cfDNA seems to be predominantly released by cells of the hematopoietic lineage (31, 37). To the best of our knowledge, no research has investigated the association between cfDNA levels based on salivary samples and exercise in an experimental setting, at least, in schools.

SB and PA are relevant factors with different effects in relation to health (3, 41) and in addition potential confounders for cortisol and cfDNA. Therefore, recent research developments with respect to SB, PA and health are outlined. With regard to public health, the relevance of SB and LPA has gained more attention recently. The authors of a recent review (42) suggested that high values in sedentary time correlated with an increased risk of cardio-metabolic disease, decreased fitness, self-esteem, academic achievement, and pro-social behavior for children and adolescent. Very obviously there is also a relation between SB and mental health, particularly depression (43). LPA seems to be beneficial to reduce obesity, overall mortality risk and should be considered for inclusion in PA recommendations (44). Therefore, it is of great importance to consider all parts of human behavior and especially to account for the compositional nature of SB, LPA and moderate-to-vigorous physical activity moderate-to-vigorous PA (MVPA). This approach has been proposed in the recent years (45, 46).

A great responsibility for children's PA and health could be assigned to educational institutions and their schedules. Apparently, students' time in school and its environment play a crucial role. Typically, NGE seem to be beneficial for promoting children's PA (47, 48), mental well-being (47) and cognition (49, 50). The amount of time children being exposed to NGA seems to be important for various health outcomes. Therefore, questions arise how the exposure to NGA and being physically active in NGA can contribute to enhance students PA and stress response during school time.

In a recent systematic literature review (51), we assessed the effects of regular compulsory school and curriculum-based education outside the classroom [EOtC, (52)] programs, focusing on students' health, PA, social, and learning dimensions. EOtC often takes place in both NGE and cultural settings. Students seem to benefit regarding learning and social dimensions. However, only one study reported improved mental health status of boys (53) and two studies (54, 55) reported higher PA levels during days with EOtC compared with regular school days. Unfortunately, the methodological quality of the 13 included studies was mostly moderate or low. Moreover, a recent large-scale study (56) on EOtC reported that the MVPA levels were significantly higher during EOtC compared with regular school days. However, the codependency among students SB, LPA, and MVPA levels remained unclear in this study. Overall, the existing knowledge on effects of EOtC with regard to PA and health is limited, despite the mentioned potentials of this type of teaching setting. Especially in the Scandinavian countries the EOtC approach is widely spread, creating good opportunities for further research (57).

In our recent publication (12), we compared the cortisol levels of students taught by applying an outdoor curriculum in the forest with children taught in the standard school setting. We were primarily interested in assessing the effect of outdoor teaching on children's normal diurnal cortisol rhythms. We reported that students in the intervention group (IG) exhibited a steady decline of cortisol levels during EOtC, whereas no such effect was observed in students in the CG during regular school days; in fact, the effect was independent of students MVPA levels. However, we could not entirely elucidate the differences in students' cortisol levels. We believe that the partial secondary exploitation of the data presented in this study is justified by the new knowledge gained, as we analyzed the cortisol and cfDNA values concerning the compositional nature of SB and PA.

This exploratory, longitudinal analysis aims to evaluate the association between students' cortisol and cfDNA levels and their SB, LPA, and MVPA in outdoor and indoor classroom environments. Based on our previous research, we assumed that different relations exist between the CG and the IG with respect to their cortisol response and PA. Specifically, we hypothesized that a decrease in students' cortisol levels can be explained by their compositional levels in SB, LPA and MVPA and explored if similar relationships exist for students cfDNA response.

MATERIALS AND METHODS

Study Design and Intervention

This exploratory analysis is part of the research project "1 year in the forest–the influence of regular outdoor lessons in a natural environment on biological indicators of stress resilience." The research in the NGE comprised a great complexity concerning measurement procedures and confounding factors. Thus, in this project, we applied a mixed-methods approach in a prospective, longitudinal quasi-experimental design. In addition, functional magnetic resonance imaging, saliva cortisol and saliva cfDNA, three-axis accelerometry, and constructs of the Self-Determination Theory were used as described by Dettweiler et al. (12).

This intervention study was conducted at a secondary school in Heidelberg, Germany. Since the school year 2013–2014, a group of fifth-grade students were taught one compulsory school day per week for the entire schoolyear in a nearby forest. The pedagogical concept of the forest teaching setting was inspired by the Scandinavian udeskole/uteskole approach as well as outdoor education from New Zealand [see (57–59) for further details]. Thus, teachers intended to facilitate student-centered, hands-on, and experimental learning situations in close connection to the NGE. In addition, this change of space within the physical setting of the "classroom" implied different opportunities for problem-solving, co-operation, experimentation, and to be physically active on students' free choice during the lessons. Furthermore, students undertook regular walks to reach specific places in the forest. Of note, the contents of the lessons in the forest setting were highly connected to the formal school curriculum and were taught in cross-disciplinary units on the forest days, including a certain variance concerning the practical relevance and season. Moreover, subject-by-subject teaching was applied on standard school days for both the IG and the CG based on traditional indoor teaching concepts [refer Dettweiler et al. (12) for further information regarding timetables and Von Au (60) for the pedagogical concept].

Participants and Data Collection

We enrolled participants from fifth and sixth grades from the school year 2014–2015. In this school year, three fifth-grade classes had forest teaching, and only one fifth-grade class had regular indoor teaching. Owing to this administrative decision of the school, we could not enroll the same number of fifth-grade students in the IG and CG. Thus, we enrolled students from a sixth-grade regular indoor teaching class into the CG; these students did not participate in the forest teaching setting during their fifth-grade school year 2013–2014. Overall, we enrolled 48 students in this study (IG, 37; CG, 11). As some students were absent during the school year, we could not collect datasets from all 48 students at all-time points in fall, spring, and summer. Furthermore, not all saliva samples provided adequate material for analysis, and accidentally acceleration sensors got lost. Of note, descriptive and enrollment data for participants is presented elsewhere (12).

We collected both samples for saliva cfDNA and cortisol using Salivette™/Cortisol- Salivette™ collection tubes (Sarstedt, Nümbrecht, Germany) at time points 08:30 a.m., 10:30 a.m., and 12:30 p.m. during the seasons fall, spring and summer. All participants were told not to eat 15 min prior every data collection. Saliva cfDNA levels were evaluated using undiluted saliva according to the protocol described elsewhere (61). After centrifuging at 1,600 × g for 2 min (room temperature), the supernatant was transferred into a new collection tube and frozen at −20°C before measurement. In addition, salivary samples for cortisol quantification were frozen at −20°C immediately after the arrival at the Biopsychology Laboratory, Technical University Dresden, and cortisol levels were determined using a commercially available luminescence immunoassay (IBL, Hamburg, Germany). Based on the validation study by Khoury et al. (62), we applied the summary indices peak reactivity (PR) and the area under the curve with respect to increase (AUCi). (For further details regarding the calculation and application of the summary indices, refer to Fekedulegn et al. (63), Khoury et al. (62), and Pruessner et al. (64) and the **Supplementary Material**, section Material and Methods).

We determined both SB and PA of the IG and CG using triaxial Axivity AX3 acceleration sensors (Axivity Ltd., Newcastle upon Tyne, UK). One sensor was attached to each child's back above the upper point of the posterior iliac crest, with the aid of a medical tape (56, 65). The sensors were worn between 08:30 a.m. and 12:30 p.m. during school time. All children were instructed not to re-attach the sensor to their skin once it fell off. All sensors were initialized at 100 Hz and ±8G bandwidth. In addition, we converted the raw vector magnitude acceleration data to ActiLife file format by an in-house software developed by the University of Southern Denmark. Children's PA levels were analyzed using ActiLife v.6.11.4 (ActiGraph, Pensacola, FL). In addition, cut-off points reported by Romanzini et al. (66) were used to distinguish SB, LPA, and MVPA; these cut-off points have been proven to exhibit a good validity among children and adolescents to identify patterns of SB, LPA, and MVPA. However, the validity and comparability of acceleration sensors, as well as applied cut-off points, have been controversially discussed. Therefore, certain differences have to be considered when comparing studies on SB and PA, especially effects of varying epoch lengths, wear time algorithms, and activity cut-points (67–69).

Statistical Analyses

In studies on PA and health, one specific behavior is often analyzed independently from other behaviors. Recent studies focused on this issue and reported that human behavior during a finite time of the day needs to be recognized as a composition that accumulates to 100% of that time. Thus, the components (e.g., sleep, SB, LPA, MVPA) are perfectly codependent and an approach that considers all parts of the composition is recommended to provide reliable evidence on human behaviors related to health (45, 46).

To set up, document and run the Bayesian hierarchical linear models (BHLMs), to evaluate associations between students' cortisol and cfDNA levels, respectively, and their relative time spent in SB, LPA, and MVPA, we applied the software packages ggthemes (70), jagsUI (71), rjags (72), and R2jags (73) in R 3.4.1 (2017-06-30) (74). The usual way to fit regression models with compositional covariates is to apply isometric log-ratio (ilr) or centered log-ratio (clr) transformations on raw values, which is justified as the parts of a composition perfectly correlate and standard regression techniques result in multicollinearity problems. However, the use of ilr or clr transformations poses problems with the interpretation, as the meaning of posterior parameter values remains unclear, especially in hierarchical models. Thus, in the given analysis, a Bayesian ridge regression version suggested by Parnell (75), which accepts raw compositions, was implemented and the raw composition values were transformed into a matrix using a common prior distribution function.

The likelihood for the applied BHLMs reads

$$Y_i \sim N\left(\alpha_{\mathrm{id}_i} + \beta_{\mathrm{cmp}_i}\left(grp_i \times x_{[1:3]i}\right) + \beta_{ssn_i} x_{4_i} + \beta_{gdr_i} x_{5_i} + \beta_{t_i} x_{6_i}, \sigma_y^2\right), \; for\ i = 1, \ldots n$$

where

$$x_{[1:3]i} = \begin{pmatrix} SB_1 & LPA_1 & MVPA_1 \\ SB_2 & LPA_2 & MVPA_2 \\ \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots \\ SB_n & LPA_n & MVPA_n \end{pmatrix}$$

denotes the matrix of the composition of the three activity behaviors, and **Table 1** presents the prior distributions of parameters in the cortisol and cfDNA models, respectively.

Furthermore, we applied a different set of priors for the respective cortisol and cfDNA models, which is justified to

TABLE 1 | The prior distribution of parameters for Bayesian hierarchical linear models.

Cortisol (BHLM 1 and 3)	cfDNA (BHLM 2 and 4)
$\alpha_{id_j} \sim N(0, \sigma_\alpha^2)$	$\alpha_{id_j} \sim N(0, \sigma_\alpha^2)$
$\beta_{cmp_j} \sim N(\mu_\alpha, 1)$	$\beta_{cmp_j} \sim N(\mu_\alpha, 1)$
$\mu_\alpha \sim N(0,\ 5)$	$\mu_\alpha \sim N(0,\ 1^{-6})$
$\beta_{tj} \sim N(0,\ 5)$	$\beta_{tj} \sim N(0,\ 1^{-6})$
$\beta_{gdr_j} \sim N(0,\ 5)$	$\beta_{gdr_j} \sim N(0,\ 1^{-6})$
$\beta_{ssnj} \sim N(0,\ 5)$	$\beta_{ssnj} \sim N(0,\ 1^{-6})$
$\sigma_y^2 \sim \mathcal{HC}(0,\ 5)$	$\sigma_y^2 \sim \mathcal{HC}(0,\ 25)$
$\sigma_\alpha^2 \sim \mathcal{HC}(0,\ 5)$	$\sigma_\alpha^2 \sim \mathcal{HC}(0,\ 25)$

id, identification of participants; cmp, composition; t, time point (midmorning, noon); gdr, gender (female; male); ssn, season (fall; spring; summer).

(a) address the well-established high-variance cortisol displays (within subjects over the course of the day with higher variance later in the day, within subjects at different seasons, and between subjects and gender) and (b) as to the best of our knowledge nothing is known about children's cfDNA levels in the saliva with respect to the daytime, season, gender, SB, and PA. In this study, we allowed random intercepts (α) for each id, and put a hyper prior to α centered to zero (i.e., inform the prior from the data). In addition, we centered βcmp on μα to tie the slope parameter βcmp to the random intercepts (equivalent to nesting ids in the groups); this is called "alternative hierarchical centering" and is an elegant way to borrow strength (i.e., statistical power) from an individual intercept and group. Putting this prior information on the composition dissolves the problem of collinearity, which is typically addressed in ilr- or clr-transformations, however without changing the scale of the output. Thus, the estimates could be interpreted straightforwardly. Finally, other priors were set to be normally distributed parameters around zero, with vaguely informed standard deviation for cortisol and super-vague informed standard deviation for cfDNA. Hence, the cfDNA model should be considered as a strictly provisional "reference model" (76).

In our analysis, we used log-transformed cortisol and cfDNA measures because of skewness and kurtosis (cf. **Supplementary Table 1** and **Supplementary Figures 3–8**). Furthermore, the Markov chains were set to 50,000 iterations, a burn-in phase of 25,000, and a thinning-rate of 10 were applied.

RESULTS

We fitted different BHLMs to assess the possible impact of the relative amounts of SB, LPA, and MVPA on students' cortisol and cfDNA levels. The BHLMs for cortisol and cfDNA differed between the applied indices PR and AUCi. In the BHLM 2 and 4 (AUCi values), the covariates group (CG/IG), gender (female/male) and season (fall/spring/summer) were included. In the BHLM 1 and 3 (PR values), the covariate time point (midmorning/noon) was additionally included. In addition, we evaluated the model fit by means of the deviance information criterion (DIC). The convergence of the Markov chains were investigated by posterior predictive checks (cf. **Supplementary Figures 7–10** for details; only the results for the respective best fitting BHLMs are presented).

Supplementary Figures 1–6 show the descriptive statistics for the variables cortisol and cfDNA, separated for the overall mean values, PR and AUCi and split by season and group. A stronger decrease of the cortisol values from 08:30 a.m. to 12:30 p.m. can be observed in IG compared to the CG, especially in the season's spring and summer. The cfDNA values show different patterns across the seasons and between the groups, which does not allow for a clear tendency. The values in fall and summer are higher compared to spring in both groups. Furthermore, only in the summer season the values of the CG are clearly higher compared to the IG. No clear correlations were found for cortisol and cfDNA with respect to group and season (cf. **Supplementary Figure 11**).

Supplementary Table 2 shows the descriptive statistics for the variables SB, LPA, and MVPA, separated for seasons and groups. We observed no evident differences between the arithmetic mean and the compositional mean in this study. Most apparent differences were observed in higher relative means of SB for the CG compared to the IG and lower relative means of MVPA for the CG compared to the IG. We neither observed any evident differences in seasons and the relative means of LPA.

Association Between Cortisol PR/AUCi and SB/PA

According to the Markov chain Monte Carlo (MCMC) posterior distributions (cf. **Figure 1** and **Table 2** for summary and **Supplementary Tables 3–4** for details), we observed a strong negative association in the IG for the relative amounts of LPA on the cortisol PR levels (posterior mean = −0.728; lower 95% credible interval [CRI]: −1.268; upper CRI: −0.190). In the CG, tendencies of a negative association were noted between SB and MVPA in the cortisol PR. Regarding cortisol AUCi, we observed the likelihood of a negative association in the IG for LPA and for a negative association in the CG for SB. Considering both posterior mean values and CIs, the IG exhibited stronger associations compared to the CG.

Association Between cfDNA PR/AUCi and SB/PA

Compared with the cortisol PR and AUCi, the results of the cfDNA PR and AUCi were different. In the IG, we observed the likelihood of a positive association between SB and MVPA in the cfDNA PR. In fact, a strong positive association was noted in the IG for SB (posterior mean, 1.285; lower CRI: 0.390; upper CRI: 2.191) and tendencies of a positive association of LPA and MVPA in the cfDNA AUCi. In the CG, tendencies of a positive association were found for LPA and MVPA in the cfDNA AUCi (cf. **Figure 1** and **Table 2** for summary and **Supplementary Tables 5–6** for details).

DISCUSSION

General Observations

We conducted the present study to provide an update on the associations between students' cortisol levels and their physical activity as reflected in the measures of SB, LPA and MVPA as

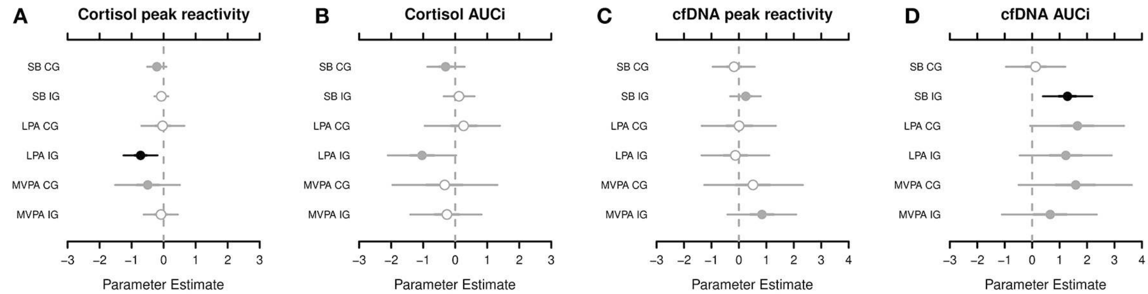

FIGURE 1 | The highest probability density for associations among the cortisol peak reactivity **(A)**, cortisol area under the curve with respect to increase (AUCi) **(B)**, circulating cell-free deoxyribonucleic acid (cfDNA) peak reactivity **(C)**, and cfDNA AUCi **(D)**, respectively, and sedentary behavior (SB), light physical activity (LPA), and moderate-to-vigorous physical activity (MVPA), segregated by groups (CG, control group; IG, intervention group). Shading, whether 50% of credible interval (CRI; gray with open circle), 95% CRI (gray with closed circle), or neither (black) do overlap 0. Black dots indicate of a strong association between the dependent and independend variable. For example, cortisol peak reactivity and LPA in the IG—the adverse effect of the relative amounts of LPA on the cortisol peak reactivity applies to, at least, 95% of children in the posterior distribution.

TABLE 2 | The MCMC output of posterior probabilities.

Variable	Model I	PM	SD	CRI 2.5%	CRI 25%	CRI 50%	CRI 75%	CRI 97.5%	Rhat	ESS
SB (CG)	BHLM 1: cortisol PR	−0.215	0.152	−0.512	**−0.318**	**−0.213**	**−0.112**	0.085	1.001	7,500
LPA (IG)	BHLM 1: cortisol PR	−0.728	0.271	**−1.268**	**−0.908**	**−0.726**	**−0.551**	**−0.190**	1.001	7,500
MVPA (CG)	BHLM 1: cortisol PR	−0.499	0.524	−1.517	**−0.860**	**−0.501**	**−0.141**	0.527	1.001	5,900
SB (CG)	BHLM 2: cortisol AUCi	−0.293	0.298	−0.880	**−0.494**	**−0.291**	**−0.095**	0.297	1.001	7,100
LPA (IG)	BHLM 2: cortisol AUCi	−1.027	0.550	−2.112	**−1.403**	**−1.030**	**−0.661**	0.062	1.001	6,700
SB (IG)	BHLM 3: cfDNA PR	0.242	0.289	−0.329	**0.049**	**0.246**	**0.435**	0.801	1.001	5,400
MVPA (IG)	BHLM 3: cfDNA PR	0.839	0.636	−0.418	**0.416**	**0.839**	**1.269**	2.088	1.001	7,500
SB (IG)	BHLM 4: cfDNA AUCi	1.285	0.464	**0.390**	**0.970**	**1.286**	**1.595**	**2.191**	1.001	7,500
LPA (CG)	BHLM 4: cfDNA AUCi	1.643	0.877	−0.072	**1.058**	**1.652**	**2.232**	3.348	1.001	4,300
LPA (IG)	BHLM 4: cfDNA AUCi	1.231	0.858	−0.455	**0.647**	**1.227**	**1.804**	2.899	1.001	5,300
MVPA (CG)	BHLM 4: cfDNA AUCi	1.574	1.053	−0.492	**0.853**	**1.588**	**2.294**	3.632	1.001	3,600
MVPA (IG)	BHLM 4: cfDNA AUCi	0.649	0.889	−1.102	**0.053**	**0.658**	**1.251**	2.356	1.001	7,500

BHLMs 1–4: variables are presented if lower 25% CRI and upper 75% CRI do not overlap 0; the respective values that do not overlap zero are bold. MCMC, Markov chain Monte Carlo; BLHM, Bayesian hierarchical linear model; SB, sedentary behavior; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; CG, control group; cfDNA, circulating cell-free deoxyribonucleic acid; IG, intervention group; PR, peak reactivity; AUCi, area under the curve with respect to increase; PM, posterior mean; SD, standard deviation; CRI, credible interval; Rhat, potential scale reduction factor; ESS, effective sample size; the ESS of the posterior distribution differs in relation to the convergence of the MCMC algorithms; the ESS depends on how accurately the proposed model fits the data.

well as associations between students' cfDNA levels and their SB, LPA, and MVPA in outdoor and indoor classroom environments. While interpreting the results of this study, one must consider the character of this exploratory study: the specific school setting in which both (a) the number of available participants is low because of the situation of EOtC in Germany, and (b) the number of possibly uncontrolled confounders is high because of the real-world scenario. However, we believe that our study can provide valuable insights into the EOtC research, health promotion in schools, and the assessment and analysis of cortisol, cfDNA, SB, and PA in the educational setting. In our previous study (12), we reported a statistically significant difference in the measured cortisol levels between the CG and IG; regular teaching in the forest correlated with a lower cortisol secretion at noon compared with the standard indoor teaching, and this association was independent of students' MVPA levels. Considering the compositional nature and, thus, the codependency of students' SB, LPA, and MVPA, we elucidated students' cortisol values during school time in this study. Furthermore, we compared those results with associations between students' cfDNA levels and their SB and PA.

According to the presented posterior distributions of the four BHLMs, the associations between students' cortisol/cfDNA levels and their compositional amount of SB, LPA, and MVPA are diverse. Furthermore, the presented effects with respect to posterior means and credible intervals must be considered as small. First, we could partially confirm our previously reported results (12) reflecting their independence of the analysis methodology, as students' cortisol levels were not affected by the relative amounts of MVPA in the IG. However, in the CG, the relative amount of MVPA is more likely to exert a lowering effect on the cortisol PR; the more active the students were in MVPA levels, the more their cortisol levels seemed to decrease. Two experimental studies (22, 23) reported that human behaviors similar to SB and LPA correlated with declining cortisol levels, which is in concordance with a typical healthy diurnal rhythm. The lowering effect of LPA on cortisol in the IG therefore corroborates Hill et al. (22) and VanBruggen et al. (23), although the specific PA intensities are not directly comparable. Thus, it could be argued that the so-called "green effect" (12, 77) in the forest (positive effects of the NGE on humans' psychological well-being) supports the lowering physiological effect of relatively high LPA levels of cortisol to some extent. Perhaps, this supportive effect could be missing during the regular indoor teaching because of the built environment. The association between SB and cortisol is more likely for the CG but not for the IG. Of note, uncomfortable sitting situations in the forest could result in psychological stress in terms of discomfort or inability to concentrate, and, therefore, potentially be attributed to this missing association in the IG. The validation study by Khoury et al. (62) reported that the PR and AUCi indices exhibit similar results regarding the cortisol increase/decrease. In this study, most associations of SB/LPA/MVPA in cortisol PR/cortisol AUCi, respectively, exhibited similar tendencies; only the tendency for a negative association of MVPA in the CG was not present for the AUCi index. Thus, we assume that our cortisol dataset based on the measurement procedure with three time points (08:30 a.m., 10:30 a.m., and 12:30 p.m.) is not entirely comparable with the time points used previously (62).

Some studies have reported that cfDNA levels already increase with moderate PA below the level of the aerobic–anaerobic transition (29, 33). The results of the cfDNA AUCi posterior distributions suggest that such an association is also more likely in both teaching settings. However, the relative amount of SB in the IG also exhibits a strong positive association with students' cfDNA values, which, perhaps, cannot be easily explained on a theoretical or empirical basis. Furthermore, the deviance values in both cfDNA PR/AUCi analyses are rather high compared with the respective cortisol values (cf. **Supplementary Tables 3–6**), which is an indication that the cfDNA MCMCs present a worse convergence compared with the cortisol MCMCs. Regarding the cfDNA, the log-likelihood is lower, and the data deviate more substantially from the models assumptions compared with cortisol. Thus, a strong positive association of SB in students' cfDNA could be likely attributed to an overestimation in the model. Regarding cfDNA results, similar tendencies have been observed between the applied PR and AUCi indices for SB and MVPA in the IG. Both indices, PR and AUCi, seem to be stable for cortisol, whereas the results for the cfDNA are more diverse regarding the PR and AUCi; this could be potentially explained by the factor "time point." As one's cortisol secretion follows a time-dependent diurnal rhythm (with expected high values in the morning and a steady decline from the noon to the evening), both validated indices account for the variation of cortisol over the period of the school day. Regarding the cfDNA, the AUCi index seems to better account for the less time-dependent and more PA-related secretion, which could be illustrated with nearly two times as much deviance for the cfDNA PR compared with the AUCi (cf. **Supplementary Tables 5–6**). In general, our analysis with the applied PR and AUCi indices was optimized for cortisol with its time-dependent diurnal rhythm and is therefore more appropriate to be used for cortisol compared with cfDNA.

Owing to the underlying pedagogical concept in the forest (60), students might have more breaks between phases of SB, LPA, and MVPA. Recent research has reported about positive health effects of breaks during extended periods of SB (78–81). The possible relevance of the number of interruptions is an interesting phenomenon to be evaluated in future research concerning students' SB and PA in school. According to the pedagogical concept of the present intervention (60), it could be hypothesized that students in the forest have more freedom to choose whether they want to sit, walk, or run. During the normal indoor teaching, students frequently have to sit still for the entire 45 min in each lesson. Perhaps, the hypothesized freedom of choice could result in better physiological reactions within students' adaptive systems. These aspects warrant further investigations. In future large-scale, prospective studies, also aspects of the sunlight exposure (82, 83) and further possible confounders should be considered.

Limitations and Future Directions

This pilot study has an exploratory character that is especially based on the relatively low number of available participants along with the mentioned high number of uncertainties in children's cortisol and cfDNA levels in relation to their SB and PA in indoor and outdoor teaching. Because of non-existing previous research in this field, a meaningful sample size calculation to determine desirable statistical power was not possible before data collection. The promising approach of retrospective design calculation (84) to inform the interpretation of gained results should be considered in general. However, this approach was not applicable in our study because of the lack of reliable external information regarding the real effect sizes. Moreover, "without relatively large sample sizes we are often precluded from saying anything precise about the size of the effect because the likelihood function is not very peaked in small samples" [(85), p. 63]. Therefore, with the results of this pilot study, gained with Bayesian inference, we do not aim to generalize our findings but rather inform prospective studies. In concordance with our previous analysis (12), three measurement points over 1 school-year provided only limited insight into the complex structure of regular compulsory outdoor lessons, students' levels of measured biological stress parameters, and the respective associations with their SB and PA. However, conducting more measurement days was not feasible for logistical and school organizational reasons. In addition, several acceleration sensors fell off because of warm weather conditions during the study time point summer, which resulted in the loss of PA data. Furthermore, we were not able to conduct a long-term cortisol analysis, as collected hair samples could not be analyzed [discussed in (12)]. Therefore, we were restricted to the measurements of saliva cortisol during the three time points at 8:30 a.m., 10:30 a.m., and 12:30 p.m. and need to assume that the salivary cortisol as an HPA axis biomarker reflects psychological and physiological induced stress with sufficient validity (24, 86). Furthermore, the allocation of students to the CG and IG was performed per the school policies and parents' choice. Thus, students could not be randomly allocated to a group by the experimenter, possibly implying certain bias. Hence, the overall small number of participants in this pilot study must be considered, and extensive, prospective studies are warranted to investigate further the tendencies explained in this study. In addition to cortisol and cfDNA the measurement of IGs should be considered in normal indoor settings. Furthermore, questionnaire-based assessment of students' mental well-being needs consideration.

CONCLUSIONS

The most important finding is that despite little difference in LPA between the CG and the IG, relative long time spent in LPA in an outdoor teaching setting seems to be strongly associated with a decline of cortisol levels, whereas no such decrease can be observed in the indoor setting. This is of great importance for educational practice, as the combination of PA and the outdoor environment during EOtC seems to be beneficial for students stress response. Additionally, the observed relative amount of sedentary time is lower and that of MVPA higher in the outdoor teaching setting in a NGE compared with the indoor setting. That implies possible health benefits for students during EOtC. Additionally, a more clinically controlled study will elucidate children's cfDNA values in relation to SB and PA, as well as to cortisol. Furthermore, in future research concerning students' PA and health in school, the co-dependency of SB, LPA and MVPA should be taken into account. Future studies on EOtC can build on the gained knowledge to apply informed priors.

DATA AVAILABILITY

The datasets for this study can be found in the **Supplementary Material**.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of and was approved by the ethics committee of the Medical Faculty Mannheim, University of Heidelberg, Germany. The approval code is 2014-585N-MA. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

PK, PS, and UD conceived and designed the study. CB collected the data. PS, SS, and EN developed tools to prepare the cfDNA-salvia probes which were statistically analyzed by CB and UD. CB wrote the paper with substantial contributions from all other authors. All authors proved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2019.00026/full#supplementary-material

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Why Have a Pet Amphibian? Insights From YouTube

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The desire to own a pet amphibian is growing, and with it a growth in amphibian trade and in negative impacts on native populations, including disease transmission and invasive amphibian populations. We know very little about how or why people choose amphibians as pets, but amphibian owners share large numbers of videos on freely accessible platforms, such as YouTube. We aimed to use videos of captive amphibians to determine which species are kept, their life-history stage and the types of videos uploaded. We watched and categorized 1,162 videos by video type, type of amphibian behavior and amphibian taxonomy (superfamily, family, and species). We used data on the amphibian trade from the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), on conservation status from the International Union for Conservation of Nature (IUCN) red list, and on potential environmental impact from published Environmental Impact Classification of Alien Taxa (EICAT) records, to determine potential conflicts of owning pet amphibians. We recorded 173 captive species in 847 videos with a taxonomic overrepresentation of salamandroids and pipoids, and an underrepresentation of ranoids and plethodontoids. When compared to videos of wild amphibian species, videos of captive animals featured disproportionate amounts of adults feeding, being handled and moving. The videos watched had a smaller proportion of threatened amphibian species, but a higher proportion of invasive species, than would be expected by chance, with the proportion present in CITES appendices (18%) being non-significant. We suggest that such data can be used to profile potential pets for trade and attempt to avoid conflicts with threatened and highly impacting alien species.

Keywords: Anura, Caudata, Gymnophiona, pet trade, invasive species, pathways

INTRODUCTION

Few would deny that amphibians are fascinating animals. Metamorphosis intrigued Aristotle (350 BP; Thompson, 1907) and other early philosophers, and continues to draw major lines of inquiry (e.g., Laudet, 2011). The subject remains in the curricula of primary school students around the world. But amphibians draw interest from a wide section of society for many other reasons, including their diverse body forms, reproductive modes, striking colors, advertisement calls and amphibious nature (Burghardt, 2017). Documentaries show a bewildering array of species with diverse behaviors in naturalistic settings to an increasingly urban audience (Wigginton et al., 2016) detached from the natural world (Miller, 2005). Is it any wonder that a wider section of society is becoming interested in having their own pet frog, salamander, or caecilian?

Trade in amphibians for pets is rising (Schlaepfer et al., 2005; Carpenter et al., 2014; Herrel and van der Meijden, 2014), but such inferences are made on a small number of databases that actually record trade in select areas of the world (Auliya et al., 2016). Most of the world's trade in amphibians likely goes unrecorded (Herrel and van der Meijden, 2014). Trade drives the collection of wild amphibians, directly leading to decline of some species (Natusch and Lyons, 2012; Alroy, 2015), and this is the justification for trade bans and/or restrictions (e.g., CITES). Trade is often injurious to the animals traded, either during transport (Ashley et al., 2014) or as a result of malnutrition and poor husbandry (Pasmans et al., 2017; Warwick et al., 2018). Trade carries disease (Fisher and Garner, 2007; Peel et al., 2012; Kolby et al., 2014; O'Hanlon et al., 2018) and specimens in trade act as reservoirs for disease (Spitzen-van der Sluijs et al., 2011). Trade can lead to alien populations becoming invasive (Hulme et al., 2008; Kraus, 2008) and these can have a wide array of impacts (Bucciarelli et al., 2014; Measey et al., 2016). Like it or not, the amphibian trade is here to stay (Garner et al., 2009). Even in the face of regional bans (Gray et al., 2015; Yap et al., 2015), illegal trade likely continues to carry the same problems (e.g., Pistoni and Toledo, 2010; De Paula et al., 2012). Despite increasing calls for banning trade, the current consensus calls for the promotion and continuation of responsible pet ownership (Pasmans et al., 2017).

Trade is fickle and subject to trends and fashions that are difficult to predict. Knowledge of what people want in a pet amphibian might help make predictions about which species may be future problems both in export and import areas. For example, the trade in dendrobatid frogs (poison arrow frogs) grew in the 1980s and 1990s (Gorzula, 1996; Carpenter et al., 2014), and was, at some point, considered unsustainable (Schlaepfer et al., 2005); however, trade in wild-caught dendrobatid frogs has now greatly diminished due to CITES and to the success in captive breeding of many of these species (Nijman and Shepherd, 2010). The African clawed frog was once exported from South Africa in large quantities (Van Sittert and Measey, 2016), but now animals are bred in and exported from China (Measey, 2017). Other examples are newts of the genus *Tylototriton* that have been exported in large numbers from Asia (Rowley et al., 2016), flooding the EU and USA markets, and consequently discouraging good husbandry (Auliya et al., 2016; Pasmans et al., 2017). Many amphibian species are difficult to keep and do not make good pets (Pasmans et al., 2017). However, we are still profoundly ignorant of what drives the amphibian pet trade, exactly what traits of species are desirable, and how can the future of trade be predicted (Reed and Kraus, 2010).

The upsurge in social media websites has been driven, in part, by the availability of cheap electronics that are able to capture sound, images, and video (Silvertown, 2009). The video-sharing website YouTube (www.youtube.com) has become extremely popular since its launch in 2005. Users can upload any video material and choose to have it available on a global platform. YouTube can censor content and users can take down videos, such that the website is somewhat dynamic. The massive potential of YouTube videos in elucidating animal behavior and human-animal interaction on a large scale (Nelson and Fijn, 2013) has spurred many studies in the last decade. These include studies on canine tail chasing (Burn, 2011), spontaneous motor entrainment to music (Schachner et al., 2009), yawning (Gallup et al., 2016) and behavior of true shrikes (Dylewski et al., 2017). Burn (2014) reviewed some of the caveats and advantages to using data from YouTube, including: non-random sampling, internal validity, large samples, and the free and ubiquitous availability. Video sharing platforms allow insight into how people perceive their pets inside their homes, and likewise the interactions that are commonly experienced with animals in the wild. So how can such data be used to assess the desire to have amphibians as pets?

We reasoned that people would upload videos of what they consider to be interesting aspects of pet amphibian ownership and wild amphibians, and that the videos uploaded would reflect amphibian taxa that are kept as pets, without reference to lists of species known to be traded. In order to gain insight into why people have amphibians as pets, we used YouTube videos to examine (i) which amphibians (species and life-history stages) members of the public are uploading videos on, (ii) whether there are conflicts for amphibians kept as pets with species that are trade restricted (listed in CITES appendices), considered threatened (according to the IUCN red list) or impacting invasive species (using the EICAT scheme), and (iii) the types of amphibian videos and behaviors that are most uploaded.

MATERIALS AND METHODS

We chose to use YouTube (www.youtube.com) as a source for prevailing interest in amphibians. We used broad search terms associated with amphibians (**Supplementary Table 1**), as well as those more specific to Anura, Caudata, and Gymnophiona, and translations of these terms in commonly used languages such as French, German, Italian, Portuguese and Spanish. Although we used search terms that were biased toward captive animals, the main subject of focus in this study, we also came across and scored videos of wild amphibians. This was done in order to understand and be able to compare behaviors found in videos of captive and wild amphibians. It was easy to determine whether videos were shot in captivity or wild scenarios, by referring to the setting in which the video was taken. However, we acknowledge that we have no information on how long any individual amphibians had been in captivity when they were filmed. To avoid dependence in searched videos, all searches were made in "incognito mode" using the Chrome browser (Davidson et al., 2010); using incognito mode allows searching without previous search history influencing the results.

From each video, we recorded the video URL, date posted, date accessed, and country of origin (**Supplementary Table 2**). Although "country of origin" was recorded as a variable, this information was present for only 42% of the dataset. We first identified the species of amphibian shown most prominently in the video, either by using information present on the video or by using expert knowledge of the authors. The video was then scored on the life-history stage of the amphibian shown, as egg, larvae, juvenile or adult. Video type was divided into wild capture, showcasing/unboxing, behavioral, culinary, captive care, educational or advertising, and scored based on our perception of the main aim of the videographer for making the video. We further subdivided the behavior of the amphibian shown into the following categories: moving, molting, mating, laying eggs, immobile, hatching, handling, feeding, dead, calling, as prey and aggression. No videos that appeared to have been made professionally or that could have been reproduced from a previously broadcasted program were included. We also avoided any re-postings of existing videos and, in cases of doubt, the content with the oldest date of video posted was chosen. The sampled videos were uploaded between 2006 and 2016.

From our identification of the subject species, we obtained the Order, Superfamily and Family according to Frost (2018) and Pyron (2014). Videos that could not be ascribed to a confirmed genus or species by the viewer were removed from analyses that required species level data but, where known, were included in Superfamily and Family groupings. This means that the dataset size differed between analyses, with a full dataset of 1,162 videos available for comparisons between taxonomic representation, video type, behavior category, and potential conflicts.

DATA ANALYSES

Taxonomic Representation

To assess over- or under-representation of amphibian orders, superfamilies or families in videos, we compared the number of species at each taxonomic level with the total number of known amphibian species (Frost, 2018), assuming a random expectation generated using the hypergeometric distribution (see Van Wilgen et al., 2018) in R (3.4.0; R Core Team, 2018). Families outside the 95% confidence intervals were deemed either over- or under-represented in our sample of YouTube videos.

Trade, Conservation, and Invasive Status

We compared species names from videos of captive amphibians with their known CITES Appendices (I, II, and III on October 4, 2017). Although the list only has 45 entries, many are for entire genera. Using Frost (2018), we determined the current composition of each genus listed under CITES, totaling 163 species/entries. Because the genus *Rheobatrachus* only has two species that are both specifically excluded, we did not include this genus. We took the same approach with the IUCN red list status, comparing species on our list to the red list status of all amphibian species (Critically Endangered CR; Endangered EN, Vulnerable VU, Near Threatened NT and Least Concern LC on October 4, 2017). Lastly, we compared our list to species of recorded invasive amphibians with known EICAT scores [Massive MV, Major MR, Moderate MO, Minor, MN, Minimal MC, Data Deficient DD, using (Kumschick et al., 2017)]. We tested the proportion of animals in the categories named above from our list with the proportion of all amphibians using a paired Wilcoxon signed rank test in R.

Comparison of Behavior in Amphibians Filmed in Captivity and the Wild

We conducted a Wilcoxon signed rank test in R on numbers of video types (not including "Wild Capture") and behavioral categories, comparing videos of wild amphibians to those in captivity.

RESULTS

Taxonomic Representation in YouTube Videos

We identified 173 captive species from 847 videos, representing 33 amphibian families (22 families and 6 superfamilies of Anura; 6 families of 3 superfamilies of Caudata; and 5 families of 2 superfamilies of Gymnophiona). For the captive amphibian videos, the majority of superfamilies were represented proportionately, the only over-represented superfamilies being the Salamandroidea and Pipoidea, while Plethodontoidea and Ranoidea were both under-represented (**Figure 1**). Similarly, most families were proportionately represented, but that some, particularly urodeles (Ambystomatidae, Salamandridae) and caecilians (Siphonopidae, Caeciliidae), were overrepresented, while frogs were generally underrepresented (**Figure 1**). Of the frog families, Scaphiopodidae, Ceratophryidae, Dendrobatidae, Pipidae, and Bufonidae were all over-represented. Only two families appear to have been under-represented, the plethodontid salamanders and microhylid frogs (**Figure 1**). The majority of videos featured only adults (88.6%), with very small numbers of videos showing the remarkable metamorphic process of tadpoles turning into juveniles (0.3%). Of the 173 different species of captive amphibians in videos, the most widely videoed frog was the Argentine horned frog, *Ceratophrys ornata* (5.6% of all videos; **Table 1**) all of which were filmed in captivity.

Trade, Conservation, and Invasive Status

The comparison of all amphibian species on CITES Appendices I–III with captive amphibians in YouTube videos was not significantly different ($V = 10$; $P = 0.125$; **Figure 2A**). Despite this, we found videos of two species listed on CITES Appendix I (*Atelopus zeteki* and *Andrias davidianus*), and we found that more than 15% of species videoed were listed on Appendix II. Proportions of threatened species (CR, EN, VU, NT) were lower in YouTube videos of captive amphibians than might be expected by chance ($V = 21$; $P = 0.031$; **Figure 2B**), although we did find videos of 13 Critically Endangered species in captivity. The number of invasive species with known impact levels (MV, MR, MO, MN, MC) in videos of captive amphibians was higher than might be expected by chance ($V = 36$; $P = 0.014$; **Figure 2C**), including species with Massive Impact (*Ambystoma tigrinum*) and some with Major Impact (*Rhinella marina, Xenopus laevis, Duttaphrynus melanostictus, Lithobates catesbeianus*). In fact, our list of captive amphibians accounts for 27.5% of alien amphibians with known impact, and 22% of all known alien amphibians.

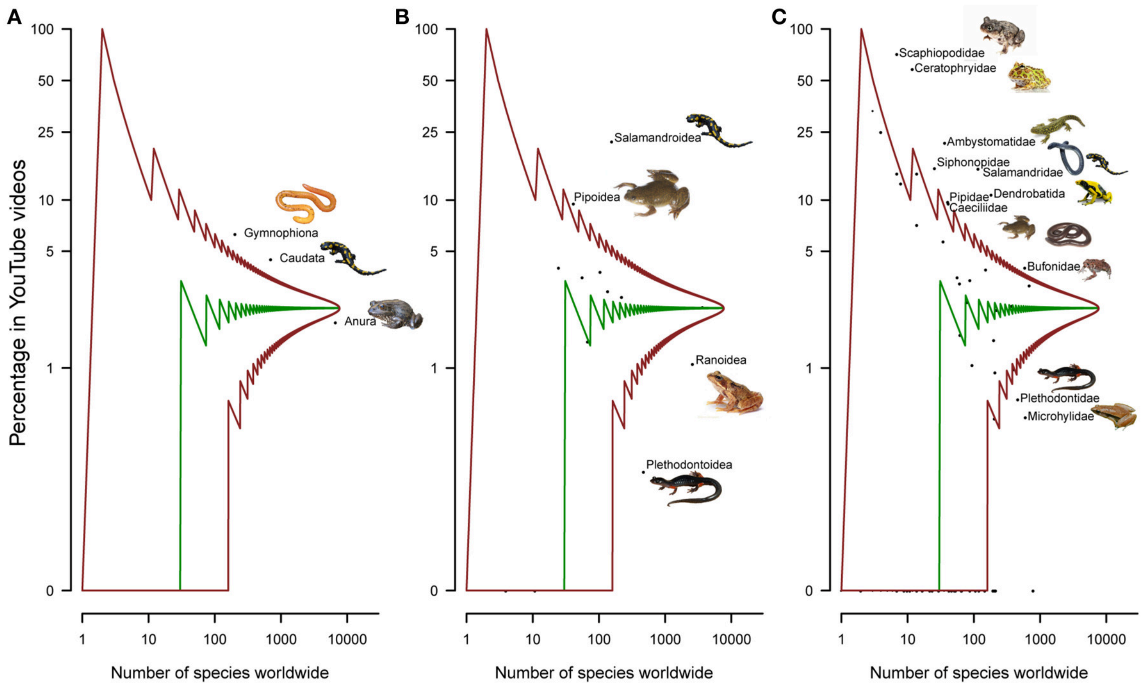

FIGURE 1 | Taxonomic patterns in amphibian **(A)** orders, **(B)** superfamilies, and **(C)** families present in the species identified in captive YouTube amphibian videos. The median (green line) and 95% confidence intervals (brown lines above and below), adjusted for multiple comparisons, were estimated from the hypergeometric distribution. The points that fall between the 95% confidence intervals are not significantly over or under-represented, relative to the number of amphibian species worldwide. Those labeled orders, superfamilies or families that fall above the 95% confidence intervals are over-represented and those below are under-represented in our sample of YouTube videos.

Comparison of Behavior in Amphibians Filmed in Captivity and the Wild

We watched 315 videos of wild amphibians, where we identified 133 species (from 22 families of the same 6 superfamilies of Anura; 8 families of the same 3 superfamilies of Caudata; and 5 families of the same 2 superfamilies of Gymnophiona). Types of videos were significantly different between wild and captive animals ($V = 70$; $P < 0.0001$; **Figure 3A**), with videos featuring different behaviors being the most frequent for both groups (49.1 and 46.8% for captive and wild videos, respectively). Behaviors of different categories were significantly different between wild and captive videos ($V = 76$; $P = 0.036$; **Figure 3B**), indicating that behaviors that could be filmed in captivity were not the same as those filmed in wild animals. For example, the most popular behavior category in captive animals, feeding (31.4%), only made up 3% of videos of wild animal behavior; for the latter, the most popular behavior filmed was movement (29.5%), which featured in only 18.7% of captive amphibian videos. Indeed, there were more films of immobile captive amphibians (26.1%) than those showing movement. The next most popular video type was showcasing or unboxing (24.8% of all videos), videos that featured newly arrived species and equipment obtained from commercial suppliers (**Figure 3A**).

DISCUSSION

Why do people want to own amphibians? Our data suggest that captive amphibians afford their owners opportunities to observe behaviors that are not observed in wild amphibians. For example, the behavior most filmed in captive amphibians, feeding, was rarely captured in videos of wild animals. Additionally, amphibians included in YouTube videos emphasized that amphibian pet ownership may be in conflict with conservation, as many species were listed as protected or threatened, as well as invasive. Our amphibian video species list contained species in all IUCN Red List threat categories (except EX and EW) but, of more concern, is that they featured a disproportionately high number of invasive species, some of which with known Massive (MV) or Major (MR) impacts. This is generally not surprising, given the high numbers of known invasive species present in the pet trade (Herrel and van der Meijden, 2014). However, we found cane toads (*Rhinella marina*) to be popular captive pets which, given their known mjor impacts is especially concerning. More than 17% of species videoed were CITES listed, with two listed on Appendix I. Of four videos of the Panamanian golden frog, *Atelopus zeteki*, one of those species, two were shot in zoos, while the provenance of the other two could not be verified. The video of a Chinese giant salamander, *Andrias davidianus*, was

TABLE 1 | The 20 most frequent captive species with videos on YouTube.

Species name	No. videos	% Videos	CITES appendix	IUCN Red List	EICAT score
Ceratophrys ornata	65	7.70		NT	
*Typhlonectes natans**	53	6.28		LC	
Pyxicephalus adspersus	31	3.67		LC	
Litoria caerulea	29	3.32		LC	
*Anaxyrus americanus**	28	3.20		LC	DD
Ambystoma mexicanum	26	3.08	II	CR	
Ambystoma tigrinum	24	2.84		LC	MV
Anaxyrus sp.*	23	2.73			
Dendrobates tinctorius	23	2.73	II	LC	
*Hypselotriton orientalis**	22	2.61		LC	
Rhinella marina	22	2.61		LC	MR
*Bombina sp.**	20	2.37			
Xenopus laevis	19	2.13		LC	MR
Dendrobates leucomelas	15	1.78	II	LC	
Lithobates catesbeianus	13	1.54		LC	MR
Salamandra salamandra	13	1.54		LC	
Bombina orientalis	12	1.42		LC	DD
Hymenochirus sp.	12	1.42			
*Siren intermedia**	12	1.42		LC	
Agalychnis callidryas	11	1.30	II	LC	
Total	473	55.69			

*For each species, the CITES appendix (if any), IUCN red list status, and EICAT score are indicated. A * against the name denotes the absence of this species from recently published lists of traded species (see text for details).*

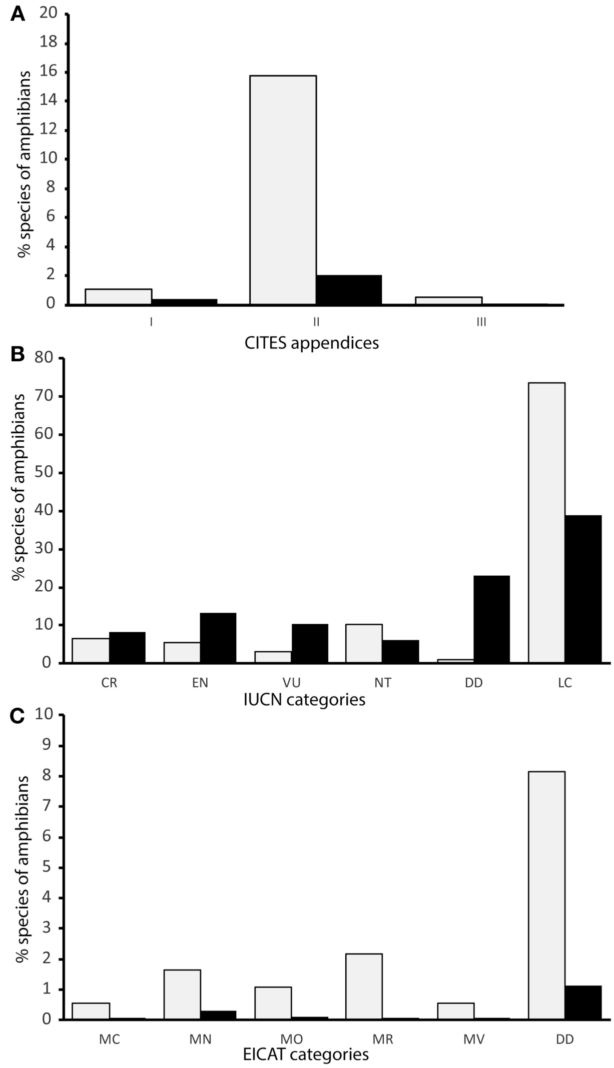

FIGURE 2 | Percentages of amphibian species identified in captive YouTube videos (gray bars) with **(A)** listed in CITES appendices, **(B)** IUCN Red List status, and **(C)** EICAT scores, compared to all amphibians (black bars). Note that in **(A)** categories "Extinct" (EX) and "Extinct in the wild" (EW) are not included, and in **(B)** the group "Not Alien" (NA) is not included, but represented 85.9% of species identified in YouTube videos ($n = 184$) and 98.3% of all amphibians. Similarly, in **(C)**, species not on a CITES appendix are not included and represented 82.6% of species identified in YouTube videos ($n = 184$) and 97.5% of all amphibians.

filmed in a Chinese kitchen and showed culinary preparation of a live animal, an act that does not contradict CITES regulations. That we found a relatively high proportion of videos with species listed in CITES Appendix II is not necessarily a conflict and may simply reflect the high numbers of these species present in the amphibian trade. Alternatively, there could be fewer CITES species in captivity because they are harder to obtain, or those that are in captivity could be filmed more frequently because of the greater interest in their rarity. However, we have no reason to think that either explanation is driving trends in our dataset.

Of the well-recorded problems associated with amphibian trade (over-exploitation, poor husbandry, disease, etc.), our data highlights the conflicts with amphibian conservation and presence of invasive species. It is not necessarily problematic that captive amphibians have a threatened status, as many threatened species are legitimately bred in captivity with legal distribution. Indeed, it could be argued that *ex situ* breeding and successful captive populations are positive aspects of the amphibian trade (Zippel et al., 2011). Problems associated with captive species that are also invasive are of more concern, as each *ex situ* population may become a potential new invasion, if animals are released or escape (e.g., Kraus, 2008). Invasions are linked to the spread of disease to native amphibian populations (Daszak et al., 1999), hybridization with native species (Ryan et al., 2009), and it is well-established that pets support a reservoir of disease (Kolby et al., 2014). Indeed, stressed individuals are likely to be immunocompromised and thus more likely to harbor increased levels of disease (Titon et al., 2017; Assis et al., 2018).

YouTube videos may not represent all people who have amphibians as pets, although we know of no reason why our sample may be biased toward particular species or behavior types. We acknowledge that the high numbers of videos "showcasing" or "unboxing" amphibians are likely to have inflated the total

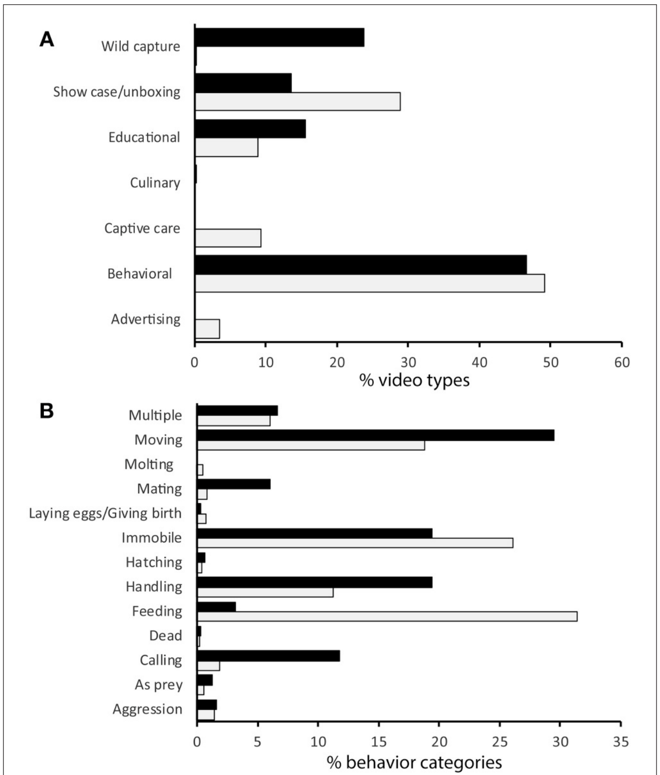

FIGURE 3 | Percentage values of **(A)** video types and **(B)** behavior categories exhibited by amphibians in captive (gray bars; $n = 847$) or wild (black bars; $n = 315$) YouTube videos.

number of species recorded, increasing the proportions of species that are rarely traded. However, these videos represented species in very low frequencies; 65% of species were only represented by one or two videos, suggesting that we could have missed a number of unusual species that are being kept in captivity. Videos featuring only the most frequent 15 captive species (video frequency >3) represented 75% of all videos watched. This species list included 10 out of the top 15 species imported live into the US (93% of individuals recorded in Schlaepfer et al., 2005; 92% of total numbers imported; Herrel and van der Meijden, 2014), 5 out of 11 species mentioned by Carpenter et al. (2014), and 11 of the 29 species available for sale in the UK (Tapley et al., 2011). The bias toward US imports may, to some extent, reflect the languages that were used in our search terms, which excluded Asian languages. Our list had only 14 of the 45 species exported live from Hong Kong (21.19% of total numbers exported; Rowley et al., 2016). Asia is clearly an important region for the amphibian trade, and conducting a comparative study on local video platforms there would be of great interest.

Our results featured groups of amphibians that, to our knowledge, are not traded, but presumably obtained directly from the wild, like the American toad, *Anaxyrus americanus*. Given that this was one of the most popular species videoed, taking amphibians directly from the wild to keep as pets may be an underappreciated aspect of amphibian captive activities. Although such instances may appear benign, releasing of immunocompromised animals from captivity back into the wild could increase prevalence of disease in natural communities (see Assis et al., 2018). The movement of wild amphibians into captivity without involving trade was given as a reason for the decline of native European species in the past (e.g., Beebee, 1973; Spellerberg, 1976). It could be an indication of the classic reason for keeping amphibians as pets: witnessing metamorphosis. We are certain that this still happens (e.g., Vigni, 2013), but does not appear to be a popular subject for YouTube videos, perhaps because it is not an easy process to film. That so few videos featured life-history stages other than adults suggests that there is proportionately little breeding of captive amphibians or, at least, being filmed. Further, if observing metamorphosis would be a prime motivation for keeping non-traded amphibians, we would expect to see a higher proportion of videos than the 8% that featured larvae and or metamorphosing amphibians.

Our search terms probably influenced our results in terms of the over-representation of salamanders and caecilians. Because it was not possible to search for amphibians and continue to find sufficient videos on which to conduct a study, we were forced to use more specific search terms. Nevertheless, the inclusion of these groups in our study does provide an opportunity to show that there are many species in captivity that were not previously considered (Schlaepfer et al., 2005; Tapley et al., 2011; Carpenter et al., 2014; Herrel and van der Meijden, 2014; Rowley et al., 2016). In future, it would be interesting to conduct a similar exercise on captive salamander videos to determine the effect of recent trade bans (Yap et al., 2015), especially to answer whether sufficient policy actions have taken place (Gray et al., 2015). Another potential source of bias in our analysis could be geographical origin of videos (Brodersen et al., 2012). However, given the lack of location information for more than 50% of the dataset (Dylewski et al., 2017), we did not investigate such patterns further. The stability of the observed patterns, in the face of the rapid growth of YouTube (Cheng et al., 2008), is a concern. However, a year-wise analysis of sampled videos does not reflect a drastic increase from 2010 to 2016, leading us to infer that the observed patterns will hold for the near future.

SUMMARY

There has been a marked increase in research into the size and effect of the pet trade, but very little attempt to explain what drives it. In this novel approach, which reaches into the homes of the owners of pet amphibians, we found that people are most interested in amphibian behavior, especially feeding. We find that behaviors filmed in captive amphibians are different from those that YouTube contributors are able to film in the wild, which we think provides insight into why people want pet amphibians: to watch feeding and movements, as well as being able to handle individuals. Our data also upholds the validity of a previously documented trend (Beebee, 1973; Spellerberg, 1976) that has received little or no recent attention: collecting native amphibians to keep as pets. Such habits may have important repercussions as these captive animals have a propensity for harboring disease (e.g., Titon et al., 2017; Assis et al., 2018), as well as other implications for conservation. Whether recent restrictions in trade will augment the collection of individuals from the local environment as pets remains to be seen. However, we caution that even in the absence of trade, keeping local amphibians as pets is still hazardous for wild populations. Lastly, our study contributes to the rapidly emerging stream of using social media to quantitatively understand human-animal interactions and further predict motivations for future interactions.

AUTHOR CONTRIBUTIONS

All authors conceived the ideas and collected the data. JM analyzed the data and led the writing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2019.00052/full#supplementary-material

Supplementary Table 1 | Search terms used in 'incognito mode' of Chrome to search YouTube for videos of amphibians.

Supplementary Table 2 | Videos watched (URL), date posted, date accessed, and country of origin. Species are identified (with Order, Superfamily, Family and Species). Videos are divided into type and subdivided into behavior.

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ORIGINAL RESEARCH
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Urban Nature Experiences Reduce Stress in the Context of Daily Life Based on Salivary Biomarkers

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Stress reduction through contact with nature is well established, but far less is known about the contribution of contact parameters – duration, frequency, and nature quality. This study describes the relationship between duration of a nature experience (NE), and changes in two physiological biomarkers of stress – salivary cortisol and alpha-amylase. It is the first study to employ long-term, repeated-measure assessment and the first evaluation wherein study participants are free to choose the time of day, duration, and the place of a NE in response to personal preference and changing daily schedules. During an 8-week study period, 36 urban dwellers were asked to have a NE, defined as spending time in an outdoor place that brings a sense of contact with nature, at least three times a week for a duration of 10 min or more. Their goal was compliance within the context of unpredictable opportunity for taking a nature pill. Participants provided saliva samples before and after a NE at four points over the study period. Before-NE samples established the diurnal trajectory of each stress indicator and these were in line with published outcomes of more closely controlled experiments. For salivary cortisol, an NE produced a 21.3%/hour drop beyond that of the hormone's 11.7% diurnal drop. The efficiency of a nature pill per time expended was greatest between 20 and 30 min, after which benefits continued to accrue, but at a reduced rate. For salivary alpha-amylase, there was a 28.1%/h drop after adjusting for its diurnal rise of 3.5%/h, but only for participants that were least active sitting or sitting with some walking. Activity type did not influence cortisol response. The methods for this adaptive management study of nature-based restoration break new ground in addressing some complexities of measuring an effective nature dose in the context of normal daily life, while bypassing the limitations of a clinical pharmacology dose–response study. The results provide a validated starting point for healthcare practitioners prescribing a nature pill to those in their care. This line of inquiry is timely in light of expanding urbanization and rising healthcare costs.

Keywords: nature pill, stress reduction, adaptive intervention, cortisol, amylase, mental well-being, duration prescription, affordable healthcare

INTRODUCTION

Exposure to nature has great benefits (Hartig et al., 2011; Ward Thompson, 2011; Bratman et al., 2012; Haluza et al., 2014; van den Bosch and Ode Sang, 2017), key among them being a better state of mental well-being (for example, Berman et al., 2008; Logan and Selhub, 2012; Hartig et al., 2014; Bratman et al., 2015; Hansen et al., 2017). While many studies show a positive influence of nature exposure on health and well-being, there is little understanding about how much or in what form a nature experience (NE) should be for best effect. Healthcare providers in North America and Europe have begun to write nature prescriptions, often called "nature pills," using common sense and interpretation of published research to motivate patients to take a nature break (James et al., 2017; Wessel, 2017). Likewise civic organizations and non-profits are emerging in support of the nature-well-being treatment such as the Mood Walks program in Canada[1], the Nature Sacred program of the TKF Foundation[2] in the United States, the Dose of Nature project in the United Kingdom (Bloomfield, 2017), and the Coastrek program in Australia (Buckley et al., 2016). Laudable examples aside, there are no quantitative studies on the frequency of nature pill prescribing and what exactly is being dispensed. There is a clear need for research that specifies the parameters of a nature pill that best support mental health. This line of inquiry on pro-active healthcare is timely in light of rising healthcare costs worldwide and the impact of growing urbanization that limits access to nature (WHO, 2016).

Dose–response approaches to the study of the nature-well-being relationship have recently been used to quantify how much and what kind of nature produces positive effects on human well-being. Theoretical frameworks for hypothesis testing and operationalizing methods have been put forward to identify the impact of duration, frequency, and intensity of a NE on health and well-being (Sullivan et al., 2014; Hunter and Askarinejad, 2015; Shanahan et al., 2015; Frumkin et al., 2017; Van den Berg, 2017). Shanahan et al. (2015) charted a framework for a more holistic consideration of what to account for in dose–response studies. The authors also discuss the key attributes of a dose–response model to identify threshold dose recommendations for specific health outcomes. Like others, they conclude that most research on parameters of a nature pill are too coarse, for example, urban versus "natural" settings, percent of foliage or green space in sight or nearby, duration of the nature interface is set by the researcher, and experiments that are often done indoors in lab settings. Frumkin et al. (2017) offer a research agenda on nature contact-health relationships while detailing the complexities of quantifying "dose."

Empirical approaches to the study of the nature dose–well-being response relationship are varied and have provided rich ways to deconstruct how the duration, frequency, and intensity of a nature dose contribute to physical and mental well-being, and how social, economic, and demographic factors adjust a dose–response relationship (Jiang et al., 2014; Shanahan et al., 2016; Cox et al., 2017a; Frumkin et al., 2017). In population-level studies, spatially grouped measures of human health and well-being are interpreted relative to the amount (dose) of nearby nature, for example, street tree density per 17 ha (Kardan et al., 2015), tree canopy per postal code (Cox et al., 2017b), and degree of urbanization per postal code (Cox et al., 2018).

Our ultimate goal is to articulate a "nature prescription" for use by healthcare providers as a preventive, self-administered health care treatment for mental well-being that is low in cost and effective in everyday settings. Full articulation of a prescription involves knowing the efficacy of which pill, at what dose, and how often. From this broad arena, we chose to start by examining the duration aspect of efficacy using objective assessment of physiological stress.

The dose–response for duration of nature exposure has been measured in a variety of ways, with the subjective assessment of mental state dominating (e.g., mood, ability to focus, and perceived level of stress, anxiety, or contentment). The subjective nature of self-report data for professional healthcare treatment decisions is considered less desirable than objectively sourced data (Van den Berg, 2017), such as change in blood pressure, heart rate, and stress hormone level. Consequently, we chose two biomarkers of physiological stress – salivary cortisol and salivary alpha-amylase, to quantify the change in physiological stress in response to the duration of nature exposure. In nature restoration studies, the hormone cortisol has proven to be an attractive biomarker of stress as it is sampled in a relatively non-invasive way through saliva collection (e.g., Ward Thompson et al., 2012; Jiang et al., 2014; Gidlow et al., 2016).

The utility of cortisol and amylase as biomarkers is predicated on being able to separate the nature exposure effect from the natural diurnal shift in production. Moreover, cortisol and amylase have distinct diurnal patterns. Salivary cortisol is highest in the morning after a brief pulse upon awakening and then drops through the day and into the night. By contrast, amylase has a distinct drop in the first hour after waking and a steady increase toward evening (Nater et al., 2007). The circadian rhythm of cortisol production in humans has seasonal shifts being lower in summertime, coinciding with earlier sunrise time (Hadlow et al., 2014). For amylase, the impact of day length is unstudied in humans, but in rats, the diurnal rhythm of alpha-amylase production changes under different photoperiod treatments (Bellavia et al., 1990). Collectively, these findings underscore the need to account for time of day for both biomarkers when interpreting the body's response to nature interventions. Most researchers accommodate the diurnal shifts by conducting experiments at roughly the same time of day, assuming the bias of diurnal change will be of equal impact regardless of day length and across participants regardless of treatment group. This approach has merit but limits what can be learned and might lead to mistaken conclusions.

Published studies using physiological criteria to investigate the impact of NE on stress are typically based on a single fixed duration time, with 15 and 30 min being the most common over a range of 10–90 min. Conclusions about the ability of a NE to influence well-being emerge from relative comparisons (paired

[1] moodwalks.ca

[2] naturesacred.org

t-test or analysis of variance) between the treatment (NE) and a control (typically an intensely urban experience). Consequently, none of these studies can be used to interpret threshold effects – minimum time for a nature pill effect, or duration-based efficacy. What is needed is a sampling method that provides nature response data over a continuum of duration times.

In terms of experimental design, randomized clinical trials (RCTs) are the gold standard for objective information on optimal dosing/exposure and the effectiveness of different types of intervention for different user groups. But, investigations about the restorative value of nature exposure are generally unsuited for the exacting protocol of an RCT. The most unavoidable conflict arises when participants and researchers cannot be blinded to the identity of the intervention, thereby introducing a perception bias (Van den Berg, 2017). Another challenge is achieving participant compliance with a behavior-based intervention (Olem et al., 2009) that (a) must be managed within the messy context of daily life, (b) is in the realm of preventive care (versus acute care), and (c) requires more time and effort than just taking a pill.

In developing an alternative approach to the RCT, our experimental design was inspired by the research of Collins et al. (2004) and Murphy et al. (2007) on adaptive intervention strategies to prevent and treat conditions that have behavioral components such as mental illness and substance abuse. Here, the course of treatment is adjusted in real time in response to what does and does not work for the individual. The behavior adaptability aspect of this approach is well suited to our goal of measuring the impact of self-directed nature exposure on mental well-being in the context of daily life for a healthy-normal population. The key difference is that our participants develop their own set of decision rules to comply with a prescribed minimum of three nature pills per week.

The experimental design presented here allows the participant to adjust terms of the nature intervention (duration, nature quality, and when it happened) for their convenience, while abiding by a set of ground rules. The goal of this adaptive intervention strategy is to introduce variation in nature pill duration and to embrace the backdrop of stress variation in daily life for a realistic estimate of effective dose. During the 8-week experiment, participants were asked to maintain a behavior regime of 3 NEs a week. Over the 2-month period, there were four tests of physiological stress, taken at the discretion of the participant (although they were asked to do so approximately every 2 weeks). Throughout the experimental period, each participant was able to customize the nature intervention in response to the constraints and unpredictability of real life by having control of the date, time of day (anytime from 1 h after rising until nightfall), and duration (10 min or more) of the NE. Use of this adaptive approach also intends to reduce some of the motivation problems that are inherent to interventions that demand greater effort and more planning than taking a pill on schedule.

The protocols for personally customized nature pills produced data that required a different analytical approach. In other stress studies using cortisol and amylase markers, the diurnal change in cortisol (daytime falling) and amylase (daytime rising) is accommodated in one of two ways. Either the participant is sampled repeatedly through the preceding day or the day of the intervention (and typically in clinical settings, for example, Rohleder and Nater, 2009) to establish the personal diurnal slope, or it is assumed that stress testing at the same time of day eliminates the contribution of diurnal change (e.g., Hansen et al., 2017). Neither protocol was useful for an experimental design based on adaptive management for self-care. To estimate a reliable nature pill prescription for members of the normal, healthy population, we present a new approach to accommodate diurnal fluctuation in the stress markers.

Our experimental goal is to investigate how relatively a short NE influences stress level within the context of everyday life using objective physiological indicators of stress. We use a repeated measures experimental design to (1) estimate the duration of an effective nature pill; (2) evaluate the impact of a NE on stress under conditions typical of the participant's daily life using an adaptive management approach; and (3) distinguish the diurnal response of the stress markers from the nature pill effect. Because proactive health care is foundational to reducing health care costs, another goal is to identify experimental approaches that improve the time and cost efficiency of research about behavioral self-care in support of better mental health.

MATERIALS AND METHODS

Selection of the Stress Biomarkers

The definition of stress varies among fields and specialties depending on what's in focus – perception of stress, behavioral response to stress, and neurophysiological response to stress. This study investigated the latter, using two known physiological biomarkers of stress. Like a pharmaceutical under test, the treatment – a NE, was evaluated for its competency as de-stressor rather than a stressor. The established biomarkers of stress – salivary cortisol and salivary alpha-amylase (hereafter, cortisol and amylase), have different pathways. The autonomic nervous system initiates adjustment to stress with signals from the hypothalamic pituitary adrenal (HPA) axis which controls cortisol, and the sympathetic adrenal medullary (SAM) axis which controls amylase (Kirschbaum and Hellhammer, 1994; Nater and Rohleder, 2009). These biomarkers are easily sampled in field settings using non-invasive, self-administered collection of saliva samples (Yamaguchi and Shetty, 2011; Nater et al., 2013b).

Cortisol is the primary stress hormone. It mediates the physical pathways of many metabolic processes involved with homeostasis including that of immune function. Prolonged elevation of cortisol interferes with learning and memory, lowers immune function and bone density, and increases blood pressure, cholesterol, heart disease, and weight (McEwen, 2008; Lupien et al., 2009). In a study of demographic and socioeconomic differences in daytime trajectories of cortisol, Karlamangla et al. (2013) analyzed data from the Midlife in the United States Study (MIDUS), and found differences in the diurnal rhythm of salivary cortisol based on age, gender, ethnicity, and education. They conclude that sampling cortisol of each participant over multiple days of a study (four times in this case) would ensure a better capture of the daytime diurnal cycle to explain some of the variation owing to differences in waking time, sleep duration, and workday versus weekend day status.

Salivary amylase is an enzyme produced by the digestive system. It is responsive to both physical and psychological stressors (Nater et al., 2007; Breines et al., 2015) and is used increasingly for stress evaluation portrayed by the sympathetic nervous system – SAM (Nater and Rohleder, 2009). Amylase is a useful marker to investigate the stress response to physical stressors (e.g., exercise, Koibuchi and Suzuki, 2014) and mental stressors (e.g., psychosocial distress (Rohleder et al., 2004; Obayashi, 2013). Amylase is also used to study of value of interventions for stress relief, most often involving physically passive interventions such as listening to music or reading (e.g., Linnemann et al., 2015). There are four studies on the impact of outdoor experience on amylase response (Kondo et al., 2018).

For amylase, there are no gender differences in diurnal response (Nater et al., 2007), although research on the complexity of the gender factor regarding the biological stress response has yet to provide a clear resolution on this point for either cortisol or amylase (Strahler et al., 2017). Research about age-based changes in amylase production has mixed outcomes regarding diurnal changes and response to stress (Rohleder and Nater, 2009), but it is clear that the stress response is different for very young children and the elderly (Strahler et al., 2017). Amylase production is much more sensitive to environmental input than is cortisol. For example, amylase is stimulated by caffeine, food or chewing itself, and exercise, and is inhibited by smoking, chronic drinking, some medicines (Nater et al., 2007). Consequently, it is important to control or account for interference from those environmental variables known to adjust amylase response.

Study Group

Participants were recruited via email announcements and flyers directed to faculty and staff at the University of Michigan and members of several local non-profit organizations in Ann Arbor, MI, United States. Recruitment focused on members of the normal, healthy population, age 18 and over, interested in spending more time outdoors in green spaces. Participants were self-selected. A minimum sample size of 30 was calculated (SAS® software, version 9.4, SAS Institute Inc., Cary, NC, United States) based on having 86% power to detect an R^2 of 0.25 using linear regression. The study had approval from the Institutional Review Board of the University of Michigan, Ann Arbor, MI, United States (IRB # HUM00089147).

In all, 44 participants were recruited, and 36 provided sufficient reliable data. Of these 92% were female (33). The mean age overall was 45.8 years (SD = 13.35, range 22–68). The sample was 86% white (31) of which two were of Hispanic ethnicity, 6% Asian (2), and 8% all others (3). Thirty-six participants had an average of 3.22 NEs (out of four, SD = 0.87).

Sampling Scheme

In accordance with our goal of defining a nature prescription for everyday life, the experimental design let participants use adaptive management to better support the behavior of taking a nature pill. Participants completed an 8-week summer study starting in mid-June 2014. The goal was to have a NE at least three times a week on days of their choice. During a NE, they could sit, walk, or do both in an outdoor location of their choice. The NE was defined as *anywhere outside that, in the opinion of the participant, included a sufficiency of natural elements to feel like a nature interaction*. Participants understood they were free to adjust the place, time of day, and duration of the NE in response to changing daily circumstances to best accommodate their goal.

The ground rules stipulated the following. The saliva sampling must take place in daylight, at least 1 h after waking and be completed before nightfall. For the 30 min before saliva was taken, there could be no eating, drinking, or toothpaste. The NE itself could not include aerobic exercise in order to limit the opportunity for an exercise-based rise in endocannabinoids. Use of social media, the internet, phone calls, conversations, or reading were also to be avoided.

Collection and Analysis of Saliva Samples

Participants provided saliva samples just before and just after a NE on 4 days during the 8-week experimental period. They were encouraged to do this at the end of the first, third, fifth, and seventh week. The collection period ran from June 17 to August 21, 2014 with a median sampling date of July 22, 2014. Almost all NEs took place in the Ann Arbor, Michigan area. Over this period, sunrise in Southeast Michigan occurred between 5:58 and 6:49 a.m. and sunset occurred between 8:47 and 9:14 p.m.[3]. Prior to each NE, (pre-NE) samples were collected as early as 7:03 a.m. and as late as 11:28 p.m.; some samples were taken outside the requested window of "before nightfall."

Training for saliva collection took place at orientation meetings where participants signed consent forms at the outset. Each participant received a small carrier with a pouch that held a blue ice pack and four pairs of Salivette tubes (produced by Sarstedt Inc.) with labels titled BEFORE or AFTER. During orientation, participants under supervision did a test run (without the NE, but with two saliva collections at least 10 min apart) using the following protocol. Just before a NE, the participant placed a cotton roll from the BEFORE Salivette tube into their mouth, chewed on it for 1–2 min (until fully wet), returned the cotton roll to the BEFORE tube, re-capped, and labeled it with their unique three-letter ID plus date and time. The process was repeated just after the NE ended using the vial labeled AFTER. At this point, the participant reported whether they had been "sitting," "sitting and walking", "walking," or "other" during the NE. When "other" was chosen, the activity type was specified. Participants also answered questions about their compliance (or lack of it) with the ground rules listed above.

Although saliva can be stored at room temperature for up to 3 weeks, freezing or at least refrigeration will prevent mold and bacterial growth (Rohleder and Nater, 2009). Consequently, participants were asked to store samples in a home or office freezer until the 8-week testing period was over at which point their entire sample set was delivered

[3] http://www.sunrisesunset.com/usa/Michigan.asp

to the lab in the carrier with an ice pack. Thereafter, samples were stored at −20°C. All protocols regarding thermal conditions of samples during transport and storage are in keeping with good practice for stability of cortisol (Garde and Hansen, 2005; Nalla et al., 2015) and amylase (Rohleder and Nater, 2009).

Frozen samples were assayed in a single batch 1 month after the close of the study for cortisol and 8 months after the study close for amylase. Concentrations of salivary cortisol and salivary alpha-amylase were measured at the Core Assay Facility, University of Michigan's Department of Psychology using commercially available kits from Salimetrics. Each assay was run in duplicate. Cortisol level was reported as μg/dL. Amylase level was reported in enzyme units per milliliter (U/mL), a number that reflects the amount of enzyme that catalyzes the conversion of 1 mmol of substrate per minute (Rohleder and Nater, 2009). The inter-assay coefficient of variation (CV) was 34% for cortisol and 65% for amylase. The intra-assay CV was 7.0% for cortisol and 3.7% for amylase. Analytical sensitivity for both stress markers was <0.007 μg/dL according to the kit manufacturer. All duplicate measures passed the check for similarity.

Statistical Analyses

The presence of diurnal cycles in cortisol and amylase highlighted the need to account for time of day. Consequently, a novel approach for accommodating time of day was developed and adopted. The samples taken pre-NE collectively established the diurnal trajectory of the study population. A comparison of stress indicator levels before (diurnal component) and after a NE (diurnal + NE components) allowed interpretation about the impact of the NE with the natural cycles of diurnal shift in biomarkers accounted for. We also investigated effects of participant activity types (sitting and walking), as well as the effect of nightfall onset on cortisol and amylase levels. Finally, the efficiency of a NE in reducing stress relative to NE duration was evaluated. A mixed model regression approach accounted for multiple measurements per participant. The model was used to establish the diurnal trajectory and to evaluate the effect of a NE on stress. Biomarkers were log-transformed to adjust for the non-linearity in each diurnal cycle. All analyses were conducted using SAS® software, version 9.4 (SAS Institute Inc., Cary, NC, United States) unless otherwise specified.

Sample exclusions were as follows. For seven NEs, at least one of the two paired outcomes (the pre-NE and post-NE samples) was not eligible. The amylase assay result was missing for two NEs, one a pre-NE and one a post-NE, so the existing data from the NE pair member was removed from consideration. Two amylase samples with levels greater than three SDs from the mean (>500 U/mL) were removed as were their NE pair members. One participant reported bicycling as the activity during three NEs. The pre and post samples for each were removed because of the capacity of aerobic exercise to influence amylase production.

RESULTS

Both stress biomarkers indicated a reduction in stress in response to a NE.

Cortisol

A NE resulted in a 21.3%/h drop in cortisol beyond that of the hormone's 11.7% diurnal drop. The efficiency of a nature pill per time expended was greatest between 20 and 30 min, after which benefits continued to accrue, but at a reduced rate.

Diurnal Response of Cortisol in Sample

The diurnal response was established with saliva samples collected just pre-NE. The Loess smoothing function was applied to untransformed data (**Figure 1**) for better visualization. The smoothed line shows a substantial drop in cortisol between waking and approximately 10 a.m., followed by a gentler decrease for the rest of the day. This pattern is consistent with published reports including one where subjects provided hourly saliva samples over the course of 1 day of normal activities (Nater et al., 2007).

To interpret the rate of change in cortisol over time, cortisol values were linearized by a natural log transformation (**Figure 2**). This transformation reduces the right-sided skew in the distribution of cortisol. A linear mixed model regression analysis of the transformed data estimated the diurnal drop in the sample population cortisol to be 11% per hour (n = 110) between morning and nightfall. This result provides a baseline for the diurnal drop, and enables us to distinguish the diurnal component of a change in cortisol level from a NE effect.

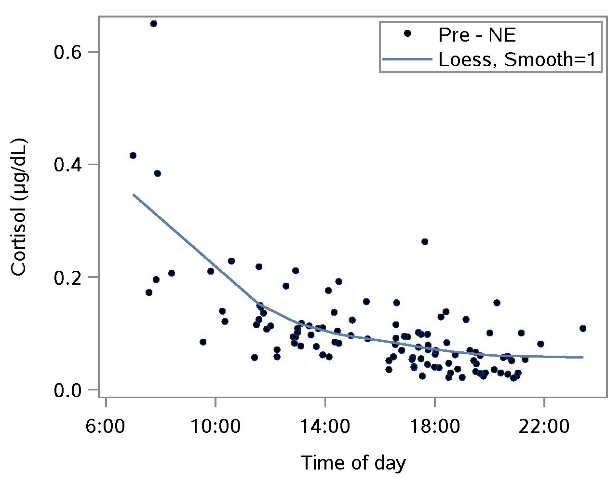

FIGURE 1 | Characterizing the untransformed diurnal response of salivary cortisol using saliva samples taken prior to a nature experience (pre- NE); n = 110 NE measurements from 36 subjects; the smoothing parameter controls the flexibility of the Loess line.

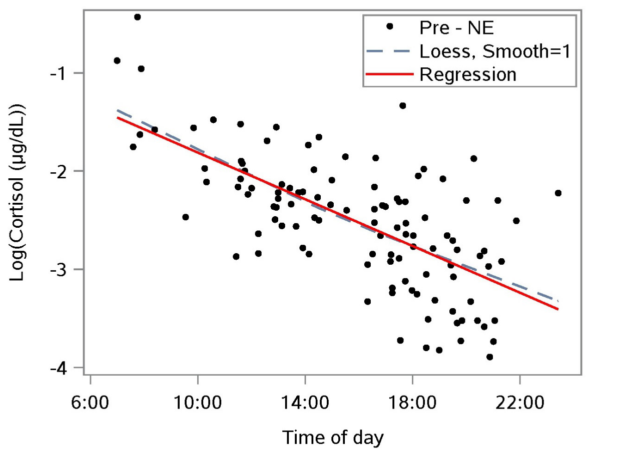

FIGURE 2 | Diurnal response of the natural log-transformed cortisol from saliva samples taken prior to a nature experience (pre-NE); $n = 110$ NE measurements from $n = 36$ subjects. A linear mixed model accounts for repeated measures per participant and estimates the relationship as log cortisol = –0.641 – 0.117 *(time of day in hours); $p < 0.0001$ for slope; the predictor "time of day" explained 41.6% of level-1 (fixed effects) variance and 51.5% of level-2 (subject-level) variance.

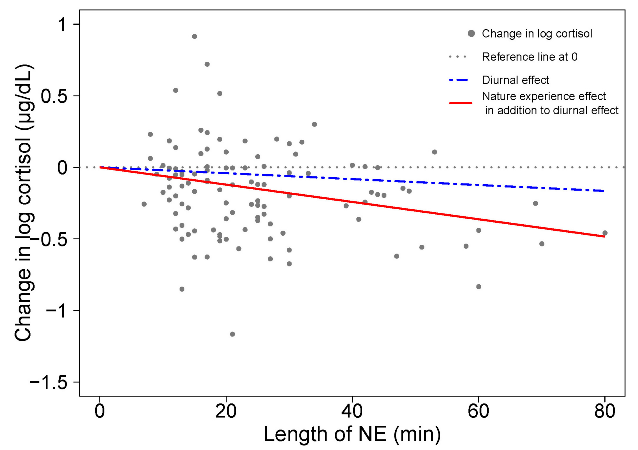

FIGURE 3 | Visualizing the contributions to cortisol change from diurnal effects and nature experience effects based on model results in **Table 1**. A scatterplot shows the change in log cortisol levels (post-NE – pre-NE log cortisol) relative to duration (length of an NE in minutes); $n = 110$ NEs. The position of the horizontal dotted line indicates an absence of both diurnal and NE duration effects on cortisol. The blue dashed line shows the estimated diurnal decrease in cortisol (11.7% per hour) while the red solid line shows the estimated combined diurnal and NE duration effects on cortisol level. The difference between the blue dashed line for diurnal effect and the red solid line is the additional effect of the nature pill. The data points (gray dots) represent the observed change in natural log cortisol levels of study participants.

Separating Diurnal Response From Estimates of Nature-Based Stress Relief

The addition of a NE duration variable (length of a NE in minutes) to the mixed model of log cortisol on time of day (diurnal effect) shows that a NE produced a cortisol drop nearly two times greater than the average diurnal drop expected during the period of the NE (**Table 1**). After accounting for the 11.7% per hour diurnal drop in cortisol in this model, NEs accounted for an additional 21.3% per hour drop.

The role of duration on the magnitude of the cortisol response is visualized in **Figure 3** as the degree of divergence between the two slopes – one for diurnal change and the other combining NE and diurnal effects over time. In the absence of a NE effect on cortisol, the coefficient for NE duration would be approximately zero, and the two regression lines would coincide. The divergence between the two regression lines indicates a NE effect on stress relief, as manifested by a cortisol drop.

Efficiency of a Nature Experience in Reducing Stress in Terms of Time Expended

To move closer to the goal of defining a reliable prescription, we used a step function model to locate the duration threshold for stress relief and the duration of greatest efficiency for stress reduction. A linear mixed model regression with change in log cortisol per hour = time of day (of saliva sampling) + NE duration interval (categorical) + NE duration (minutes) was fitted to the sample. Time of day for pre-NE samples captures the impact of a natural diurnal drop over the course of a NE. The NE duration interval variable, a categorical variable for the step function, was created with quartile partitioning. Because the NE start and stop times were reported in full minutes, the quartile partitioning is not at exactly 25%. The intervals shown in **Table 2** gave the most equitable distribution of samples while accommodating the left-skewed distribution of the NE duration variable.

A step function model of NE duration (**Table 2**) shows a significant reduction in the stress hormone cortisol after a NE greater than 20 min. Stress relief was most efficiently gained when a nature pill lasted between 21 and 30 min when cortisol dropped at a rate of 18.5% per hour beyond diurnal effects.

TABLE 1 | Estimating the change in cortisol by duration of the nature experience (NE duration in hours), after accounting for the natural diurnal effect (time of day).

Effect	df[A]	Beta	Standard error	*p*-value	% Cortisol decrease per hour[B]
Intercept		–0.542	0.1952	0.0064	
Time of day (diurnal effect)	109	–0.124	0.01179	<0.0001	11.7%
Length of NE (NE duration)	128	–0.239	0.05815	<0.0001	21.3%

[A]Denominator degrees of freedom [B]Calculated as e $^{beta\ estimate}$ – 1. The diurnal effect is expressed as percent change per hour of log cortisol. Linear mixed models were used to account for multiple NEs per person (36 subjects, n = 220 saliva samples from 110 NEs). This model explains 26.9% of level-1 (residual – repeated measure) variance, 47.9% of level-2 (subject-level) variance, and 53.7% of level-3 (timepoint-level) variance.

TABLE 2 | Efficiency of a nature experience in reducing stress in terms of time expended.

Effect		*n*	Beta	Standard error	*p*-value	% Cortisol drop/hour[A]
Intercept		110	−0.52	0.197	0.009	
Time of day (diurnal effect)		110	−0.125	0.0119	<0.0001	11.7%
Duration interval: length of NE (min) per quartile[B]	**NE frequency for each minute in the interval**	***n*/% of total sample**				**% Cortisol drop beyond diurnal effect[A]**
Q1: 7–14 min	1,2,1,2,5,7,7,3	28/25.5%	−0.0864	0.0561	0.13	8.3%
Q2: 15–20 min	5,2,8,1,6,5	27/24.5%	−0.0375	0.0572	0.51	3.7%
Q3: 21–30 min	4,1,3,2,6,4,3,1,1,5	30/27.3%	−0.2048	0.0545	0.0003	18.5%
Q4:>30 min	1,1,2,1,1,1,1,2,1,2,1, 1,1,1,1,1,1,2,1,1,1	25/22.7%	−0.1214	0.0600	0.045	11.4%

[A]Calculated as $e^{\text{beta estimate}} - 1$. [B]Reported in minutes, calculated as proportion of an hour. Mixed models of log cortisol levels as predicted by diurnal effects (time of day) using a linear function and by duration of a nature experience using a step function. The step function estimates are calculated for each quartile interval (Q) separately and are not cumulative. This model explains 26.7% of level-1 residual [repeated measure] variance, and 45.9% of level-2 [subject-level] variance, and 53.4% of level-3 [timepoint-level] variance.

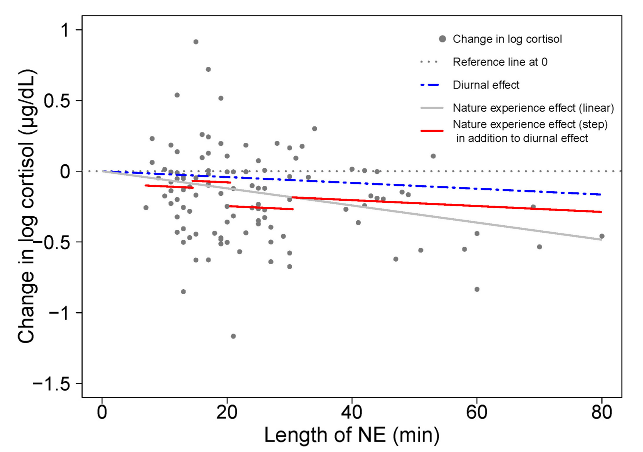

FIGURE 4 | A visual comparison of cortisol response to NE duration with linear (gray solid line) and step function regressions (solid red line segments) based on the results shown in **Tables 1** and **2**. As in **Figure 2**, the blue dashed line represents the diurnal effect of change in log cortisol. The difference between the blue dashed line and the red solid line segments represents the nature experience effect in addition to the diurnal effect.

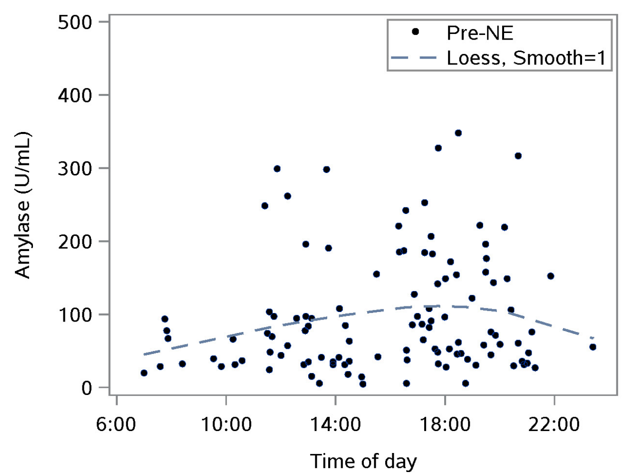

FIGURE 5 | Characterizing the untransformed diurnal response of salivary amylase in our sample using pre-nature experience (NE) amylase levels for all NEs; *n* = 110 NEs from 36 subjects; the smoothing parameter controls the flexibility of the Loess line.

Thereafter, benefits continue to accrue, but at a reduced rate of 11.4% per hour.

A visual comparison of linear and step function regressions for the cortisol response to NE duration provides insight on the nature of the variation in the linear model (**Figure 4**). Investigation using a step function offers a way to uncover the relative restoration efficiency of different nature pill durations and provides a guidance on optimal duration of a nature pill in terms of cortisol drop/stress relief efficiency.

Amylase

A NE resulted in a 28.1%/h drop in amylase after adjusting for its diurnal rise of 3.5%/h, but only for participants that were least active sitting or sitting with some walking. Activity type did not influence cortisol response.

Establishing the Diurnal Response of Amylase

Salivary amylase levels measured pre-NE showed the expected diurnal form of untransformed data: a rise from morning to some point in the evening after which, amylase falls until morning (**Figure 5**).

After log transformation to normalize pre-NE amylase data (due to its right-sided skew), a linear mixed model for diurnal effect was fitted to the data ($n = 110$): log amylase = 3.8 + 0.027*(time of day in hours). The 95% CI for the slope was (−0.0036, 0.05763), indicating that the slope was not significantly different from zero (p-value = 0.084). This was unexpected given the outcomes in other field studies showing a rising diurnal amylase response (e.g., Nater et al., 2013b). Our study differed from others by its inclusion of saliva samples from NEs completed after nightfall. Although the impact of day length on amylase production is unstudied in humans, its production changes when under different photoperiod treatments in rats (Bellavia et al., 1990). In our study, all NEs began sometime after dawn but seven of the 110 NEs ended after dark – in violation of the ground rules given to participants. Consequently, we tested a set of hypotheses to identify the time of day when the direction of amylase production shifted. This investigation became the basis for deciding which saliva samples would not be included.

Estimating the Time of Directional Shift in Diurnal Amylase Response

The investigation used two approaches to identify a reliable cutoff point for NE data inclusion based on the timing of the shift in the direction of diurnal amylase production. First, we compared the slopes from a set of linear mixed models using NE datasets that had cutoff times set one hour apart from 6 p.m. through midnight. This approach gave the opportunity to compare our results with those of several other studies that ended between 4 and 8 p.m. The mixed model with the largest slope (beta) came with NEs completed by 9 p.m. (**Table 3**). Nine in the evening was close to the average sunset time of all NEs – 9:04 p.m., during the experimental period that ran from June 17 (sunset at 9:14 p.m.) to August 21 (sunset at 8:47 p.m.).

Next, we considered the role of sunset time, specific for the date of each NE. Data on time of sunset (civil twilight) in Ann Arbor, MI, United States, in 2014 came from http://www.sunrisesunset.com/usa/Michigan.asp. The best linear fit for the amylase diurnal response came from the data set delimited by a sunset criterion: post-NE saliva samples were taken before the time of sunset on the NE date (**Table 3**). Consequently, the remaining analyses of amylase response include only those 103 NEs that ended before sunset. It is of note that a comparable test with cortisol data showed that inclusion of the NE's happening post sunset had no influence on the diurnal trajectory of falling cortisol based on model fit. This was expected as there is no shift in the direction of diurnal production of cortisol until a rapid escalation upon morning rising (Hadlow et al., 2014).

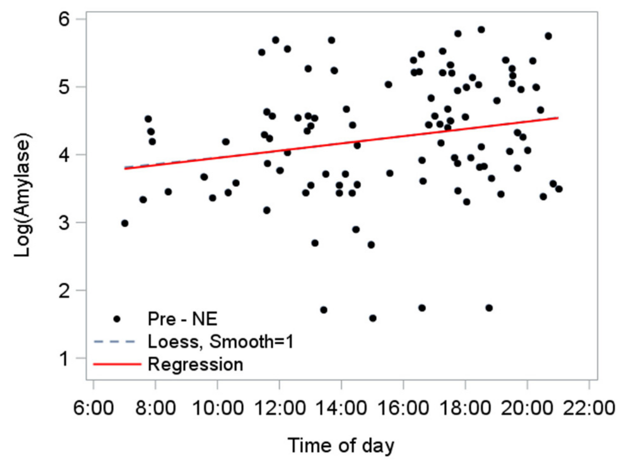

FIGURE 6 | Diurnal response of amylase for NEs completed by sunset (n = 103). A mixed model accounts for repeated measures per participant and estimated the relationship as log amylase = 3.7 + 0.036*(time of day in hours), 95% CI for slope (0.0051, 0.067), p = 0.023. The predictor "time of day" explained 4.3% of level-1 (fixed effects) variance and 4.8% of level-2 (subject-level) variance. The position and flex of the Loess line (dashed) nearly mimics the path of the model's regression line, corroborating the model fit.

We established the diurnal baseline response of amylase using pre-NE saliva samples from NEs that ended before sunset (n = 103; **Figure 6**). The diurnal rise in amylase over the day until sunset was estimated at 3.7%/h, based on the slope (0.036) from the linear mixed model fitted to pre-NE log amylase: ($e^{0.036}-1$).

Effect of Different Types of Physical Activity on Amylase

No significant effect of NE duration on amylase was detected in a linear mixed model that controlled for diurnal effect (p = 0.21, beta = −0.116, n = 103 NEs). The discrepancy between this result and that of the cortisol biomarker led us to reconsider a key assumption of the amylase model: that activity type did not differentially influence amylase response. Note that most

TABLE 3 | Mixed model linear regressions of pre-NE log amylase on time of day using eight subsets of the data, each differing by the latest time of the post-NE saliva sample.

Pre-NE samples from NEs ending as late as:	Beta	*p*-value	*n*	Subject number	Den df
6:00 p.m.	0.04640	0.1374	67	33	54.2
7:00 p.m.	0.04339	0.0681	79	34	61.2
8:00 p.m.	0.03149	0.0871	91	34	68.5
Sunset – time varies	0.03584	0.0230	103	35	78.7
9:00 p.m.	0.03253	0.0393	100	35	75.0
10:00 p.m.	0.02831	0.0622	108	36	84.1
11:00 p.m.	0.03064	0.0529	109	36	84.1
12:00 a.m.	0.02699	0.0835	110	36	88.9

Each hourly interval includes all NEs that started after 7 a.m. and ended by the time shown. By contrast, the sunset model includes NEs that ended by the time of sunset on the date of the NE. Regression slopes and p-values are reported. Denominator (Den) degrees of freedom (df) reflect the amount of information for regression error in the correlated repeated measures data.

research on the amylase-physiological stress relationship focuses on athlete training and implies that amylase is elevated only with more intense activity types (Koibuchi and Suzuki, 2014; Peinado et al., 2014). The following paragraphs reveal how we determined that (a) sitting and sitting+walking during a NE produced very similar outcomes in terms of amylase production despite sample size differences; (b) amylase production in the non-aerobic walkers was extremely different than amylase production in the two sitting groups; and (c) the amylase response when sitting or sitting+walking was very similar to that of the stress hormone cortisol (which is not sensitive to activity type).

To test our assumption, we needed to determine whether participant and activity type were confounded in this repeated measure design. We found that 36 participants did not choose the same activity type for each NE: 21 participants engaged in 31 "sitting" NEs, 12 participants engaged in 17 sitting+walking NEs, and 23 participants engaged in 55 "walking" NEs. The average diversity of activity types per individual was 1.64 out of 3 (SE = 1.05); 44% stuck with one activity type, 47% used two types, and 8% used all types.

Next, we looked for differences in amylase response as a function of activity type. A linear mixed model with a three-category covariate for activity type (sitting; sitting+walking; walking only) was fitted to the log transformed amylase data (**Table 4**, Model 1). Activity type was associated with a notable difference in amylase response (with diurnal changes accounted for): a walking NE produced a 4% drop per hour versus a sitting NE (34% drop per hour) or a sitting+walking NE (30% drop per hour).

Next, we grouped data from the two lowest exertion classes (sitting and sitting+walking) based on the similarity of the amylase responses (i.e., regression slopes). The linear mixed model with a two-category covariate for activity type (**Table 4**, Model 2) showed that lower exertion nature pills had an amylase drop of 27.9% per hour (with diurnal changes accounted for). Higher exertion nature pills had amylase changes that were indistinguishable from the baseline diurnal condition. **Figure 7** visualizes these relationships.

Unlike cortisol, amylase data could not be used to estimate what duration period was most efficient for stress reduction because separation by activity type led to inadequate sample size.

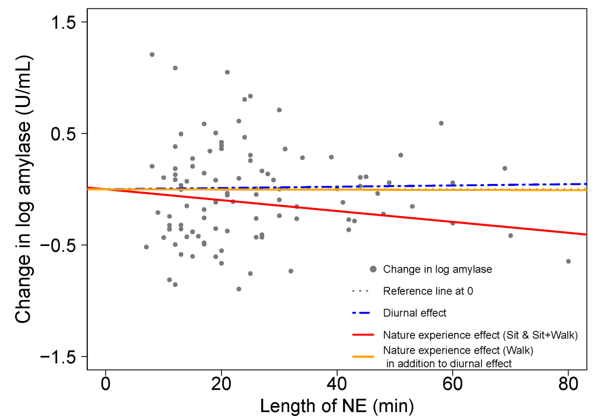

FIGURE 7 | Visualizing the contributions to amylase change from start to end of the NE due to diurnal effects and nature experience effects for two activity types; based on model results in **Table 4**. A scatterplot shows the change in natural log amylase levels (post-NE – pre-NE) relative to duration (length of an NE in minutes); *n* = 103 NEs. The position of the horizontal dotted line (black) indicates an absence of diurnal and NE duration effects on amylase. The blue dashed line estimates the diurnal increase in amylase (+3.5%/h) while the solid lines (red for NEs while sitting and yellow for NEs while walking) estimate the combined effects of the circadian cycle and duration of an NE on amylase level. The difference between the blue dashed line for diurnal effect and the red solid line is the additional effect of the nature pill. The data points (gray dots) represent the observed change in natural log amylase levels of study participants.

It is important to point out that the regression of cortisol on NE duration produced the same slope for low and high exertion categories (**Table 5**). Based on a comparison of low exertion conditions such as sitting (**Table 6**), we conclude that the NE-based decline in cortisol and amylase are comparable when a nature pill is taken, but that cortisol is a more robust biomarker for field studies.

DISCUSSION

The field study presented here offers the first estimates of the impact of NE duration on stress level in the context of normal

TABLE 4 | The effect of physical activity type on amylase.

Activity type (# participants, #NEs)		Time of day (h)/diurnal effect		Length of NE (h)/duration	
	n	Beta	*p*	Beta	*p*
Model 1. Activity levels					
Sitting (21, NE = 31)	62	0.034	0.013	−0.34	0.08
Sitting + walking (11, NE = 17)	34			−0.30	0.30
Walkers (23, NE = 55)	110			−0.04	0.70
Model 2. Activity levels grouped					
Sitting and sitting + walking (NE = 50)	96	0.034	0.013	−0.33	0.047
Walkers (NE = 55)	110			−0.04	0.702

Mixed model linear regressions of log amylase on time of day (diurnal effect), duration of the nature experience, and activity type during the NE. Model 1 includes three activity levels; Model 2 collapses "sitting" and "sitting + walking" to distinguish the two lower activity groups from the highest activity group "walkers" (n = 206 amylase measures from 103 NEs).

TABLE 5 | Effect of physical activity type on cortisol.

Activity type (# participants, #NEs)		Time of day (h)/diurnal effect		Length of NE (h)/duration	
	n	**Beta (SE)**	***p***	**Beta (SE)**	***p***
Sitting (21, 33) and Sitting+walking (11, 17)	100	−0.124 (0.012)	<0.0001	−0.240 (0.010)	0.023
Walkers (23,60)	120			−0.239 (0.068)	0.0006

Mixed model linear regression of log cortisol on time of day (diurnal effect), duration of the nature experience, and two activity groups (n = 220 from 110 NEs).

TABLE 6 | Rate of change in two stress biomarkers per hour due to underlying circadian rhythm (diurnal effect) and activity types; based on model outcomes for cortisol in **Table 5** (NE = 110) and for amylase in **Table 4**, Model 2 (NE = 103).

Effect	Model beta	% Cortisol change/hour	Model beta	% Amylase change/hour
Diurnal effect	−0.124	−11.7%	+0.034	+3.5%
NE duration while sitting or sitting + walking	−0.240	−21.3%	−0.33	−28.1%
NE duration while walking only	−0.239	−21.3%	−0.04	−3.9%

For negative slopes, % drop is calculated as (1 – e $^{\text{beta estimate}}$); for positive slopes, % rise is calculated as (e $^{\text{beta estimate}}$ – 1).

daily life. Spending time with nature produced a significant drop in the stress hormone cortisol, with the duration of the NE contributing to the amount of stress reduction. The research also breaks new ground in the following ways, primarily by addressing some of the complexities of measuring an effective nature dose. First, it directly investigates the duration aspect of a successful nature pill prescription in the context of real life. Second, the 8-week field experiment enabled repeated measures of each participant in different contexts, thereby allowing the circumstance of an individual's daily life into prescription development of the nature pill. Third, an adaptive management approach allowed participants to self-manage the time, place, and duration of each nature pill to offset the inevitable challenges of scheduling a non-essential activity. Fourth, a novel approach to data evaluation offers a way to distinguish nature pill effects from diurnal effects without repeated invasive saliva sampling for baseline physiological status throughout the day of an NE. Finally, the results provide a validated starting point for healthcare practitioners prescribing a nature pill to those in their care.

Cortisol

Cortisol Response: Recommendation for a Nature Pill Prescription in Terms of Duration

Two models with good fit investigate the trajectory of cortisol in terms of duration of the NE. The linear model of change in log cortisol on NE duration predicts a stress reduction of 21.3% per hour. Because people find it difficult to make time for self-care, a step function model asked the question: what is shortest duration needed to achieve benefit? We found that stress relief is significantly and most efficiently gained (18.5% cortisol drop/h) when the nature pill lasted between 20 and 30 min, and significant benefits continued to accrue thereafter at a somewhat reduced rate (11.4%/h). This is a useful and robust starting point for a nature pill script because it emerged from an adaptive management platform, embracing the typical variation in how people make or use their free time. Needless to say, the true functional form of the response will require further testing with a larger sample size, an expansion of the duration times (especially < 10 and 31–60 min), and sample populations with a broader age and gender representation.

Distinguishing Nature Pill Effects From Diurnal Changes in the Stress Markers

A population response to NEs is a useful basis for defining parameters of a nature pill prescription where parameters are largely controlled by the participant rather than the researcher. We were able to evaluate the impact of a NE *in situ*, using a population approach to provide a reliable estimate of the baseline diurnal pattern of each stress marker. Mixed model regression to handle repeated measures could distinguish the difference between an expected change in stress markers (diurnal effect) and realized change in stress markers at the end of a NE (NE-based effect).

Accurate assessment of diurnal drop of cortisol is key to accurate assessment of a nature pill effect. Further support that our diurnal cortisol drop of 11.7% per hour is robust comes from the results of three repeated measures studies with similar outcomes to ours, despite differences in experimental goals. In all cases, participants went about their daily life during the study. The key difference between our study and the studies described below is that our study estimated the diurnal response of cortisol with a single saliva sample (pre-NE sample) per participant on each sampling day. The other studies estimated diurnal cortisol with four to five saliva samples per participant on each sampling day.

Laudenslager et al. (2013) reported an 11.0% per hour drop in diurnal cortisol over a period of 10 hours beginning 30 min after waking ($p < 0.0001$; 95% CI: −13, −9%). The study was focused on testing a novel saliva collection device to support participant-controlled field sampling. The study had a similar sample to ours: 32 participants, 81% female, 18% were not Caucasian, and the age range was roughly the same as our study. The only restriction on participants' behavior was to avoid eating, teeth brushing, and drinking liquids within 15 min before saliva sampling. The design used repeated measures: each participant collected saliva for 3 consecutive days at four time points in the day. A linear mixed model regression included log transformed cortisol data and collection time of day. There was some allowed flexibility in the collection time of saliva: at awakening (flexible), 30 min post awakening, just before lunch (flexible), and 10 h after waking. Compliance with collection time for the second and fourth sample of the day was not perfect, yet tolerance testing for 7.5 and 15 min offsets revealed no significant effect.

In a study of quality of life in relation to demographic and socioeconomic differences, Karlamangla et al. (2013) analyzed data from 1693 participants whose ages fell within the same range as our study; 57% female and 86% Caucasian. Participants provided saliva samples on 4 days over a week's period that included both weekdays and weekend days. On each sampling day, saliva was taken: at awakening (flexible), around 30 min post awakening, just before lunch (flexible), and at bedtime (flexible; median bedtime was 10:30 p.m.). This produced significant variability in actual time of sampling and allowed examination of cortisol level across the entire day in the sample population "to get a general idea of the shape of the mean daytime cortisol trajectory" (pg. 4). They reported a cortisol diurnal drop of 8.1% (beta = −0.084) for a 10.5 h period that began 4.5 h after rising. This temporal division of data was enabled by a high sample size (>24K cortisol data points), and the use of the more flexible linear spline model. Their model was also indexed on "time since waking" and adjusted for a participant's average length of waking day, length of sleep the previous night, waking time on day of measurement, and weekend versus workday status.

Nater et al. (2013b) report a mean diurnal cortisol drop of 12.2% (beta = −0.13) in an investigation of diurnal cortisol and amylase profiles over adult life span. The study included 185 participants (median age of 49, 51% female, 74% Caucasian) who provided a saliva sample five times per day on each of seven test days over a 10-day testing period. The estimate of mean diurnal cortisol drop was based on the difference in cortisol level at waking and the last sample of the day (9:00 p.m.), taking respective time of day into account. Sample times throughout the day were: at awakening, 30 min later, 9 a.m., 12 p.m., 3 p.m.,6 p.m., and 9 p.m. At these times, participants provided a saliva sample and answered a questionnaire.

In light of these comparisons, we conclude that our experimental design and analytical approach offers an efficient way to investigate the value of self-care behaviors in preventive health care that rely on adaptive management. Our approach is also an alternative to experimental designs that require more control over participant behavior, such as pharmacology dose–response or clinical trial testing. We recognize that our experimental approach is possible largely because the nature pill intervention is not dangerous if misused. The relative safety of a nature pill in any dose is one reason that health care professionals around the country feel comfortable prescribing nature pills to patients without the benefit of guiding data.

Comparison of Cortisol Results From Other Outdoor Studies of the Nature Effect

The results of our repeated measures study can be considered in light of field studies that use cortisol to assess the impact of single episodes of nature exposure on psychological stress. Japanese studies of Shinrinyoku – immersing oneself in nature by mindfully using all five senses (Tsunetsugu et al., 2010; Hansen et al., 2017) have provided recurrent support for the ability of nature to reduce stress. The protocols are well considered and meticulous and are akin to those of most other field tests of nature's stress reducing potential.

Park et al. (2010) complied data from many studies done under exacting conditions that compared salivary cortisol levels of male college students (n = 280) who spent time in forest and nearby urban settings (the control) in 24 National Forests of Japan. Subjects were housed in controlled settings on the nights preceding testing days. In each National Forest and at the same time of day, 12 participants spent 15 min sitting while viewing either the forest (n = 6) or a nearby urban setting (n = 6). Participants were tested likewise on a consecutive day in the alternative setting (random crossover trial). Before and after a 15-min test interval, saliva was collected (comparable to our method). A pairwise means comparison of the two treatments (forest versus urban setting) showed that the average salivary cortisol level of participants was 13.4% lower after 15 min of forest viewing while sitting compared to urban viewing. For just over a third of the sample group (∼75), the 15-min sitting period was preceded by a 15-min walking period in the forest. Cortisol was 15.8% lower after 15 min of forest walking compared to participant's response to walking in the urban setting. Diurnal effect was ignored as testing time was approximately the same for both treatments. Using the same experimental approach, Park et al. (2012) expanded the database to include 420 participants at 35 different forests throughout Japan. They reported that participants walked their assigned areas for 16 ± 5 min, then sat and viewed the area for 14 ± 2 min. They reported a 12.4% drop in salivary cortisol after the forest experience compared to the urban experience. Kobayashi et al. (2017) point out that although the time of saliva collection varied from 9 a.m. to 12 p.m., each participant was measured at approximately the same time on each experimental day for both environments.

Unlike the Shinrinyoku research, our study yields NE outcomes in terms of an hourly rate of stress reduction after diurnal effects are taken into account. Our linear model reveals the overall stress reduction of cortisol at 21.3% per hour. Interpolation from this model predicts a 10.6% cortisol drop after a 30 min NE. By contrast, the Shinrinyoku studies report a 12–15% cortisol drop after a 15-min period of forest sitting. We consider these outcomes quite similar considering that several modifiers are likely in play. Acclimation to field setting: Shinrinyoku participants spent time getting accustomed to the setting before the first cortisol sample was taken (walking from transport to the field site and spending time at the field site for several other physiological measures). Additionally, participants had a low stimuli common experience for at least 12 h preceding the field test. By contrast, our experiment had significantly lower level of control over participant behavior before and during the field tests because of the adaptive intervention strategy. Quality of the "nature" setting: Shinrinyoku took place in national park settings which brought sensory continuity to the experience of all participants and offered a consistently high opportunity for a sense of nature immersion. By contrast, there was variation in our participant's choice of each NE setting, typically in urban green space near enough to be convenient. Finally, Shinrinyoku testing was done over 2 days with participants removed from their daily routine and led under the direction of researchers versus the adaptive management situation that requires a self-motivated decision to take a nature break when time permits within daily life. Overall, we think that the results of our adaptive intervention dose–response study are coherent with other studies given the differences outlined above. The source of these differences also makes clear the need to move forward with a focus on additional dose–response studies that use comparable methods to identify minimum dose recommendations for specific health outcomes.

Amylase

Amylase Response: Corroboration With NE-Based Cortisol Response

It is of note that our amylase results for the impact of a NE on stress corroborate those of cortisol. When low exertion nature pills were evaluated, the degree of restoration indicated by amylase (28.1% per hour, n = 50 NE) is comparable to that of cortisol (21.3% per hour, n = 110 NEs). The slightly larger restoration value for amylase may be related to differences in time of production and release of these stress markers. In a study of response to acute stress, salivary alpha-amylase response was faster than cortisol (Takai et al., 2004).

As with cortisol, our analytical approach required a reliable estimate of the amylase diurnal baseline. Our study showed a 3.5% rise in amylase from 1 h after rising until sunset. We could find only two relevant studies reporting diurnal amylase response in terms of a slope. Both gave results comparable to ours. Nater et al. (2013a) report a mean diurnal amylase rise of 4.1% (beta = +0.04) in an investigation of diurnal cortisol and amylase profiles over adult life span. Details about this work are given above (section "Amylase").

Out et al. (2013) reported a 2.15% increase in salivary amylase from waking to evening in a repeated measure study (n = 122 participants) involving five saliva samples per day for each of 3 days in five sampling periods between August and February. These data also indicated that variation in diurnal response within an individual varied by less than 1%. From this, Out et al. (2013) and others cited in their paper suggest that diurnal amylase profile is relatively stable compared to the response to momentary stress and ongoing moderate stress of both physical and psychological origin.

The Utility of Using Salivary Amylase for Studies of Nature-Based Stress Relief

The inclusion of salivary amylase in this NE study adds to the growing body of information about the value of using this stress marker in restoration studies. Using amylase to evaluate calming interventions such as communing with nature uncovered two confounding effects: the sensitivity of amylase to physical exertion and time of sunset.

Amylase Sensitivity to Time of Sunset

Our data define a diurnal rise in amylase of 3.5% per hour over daylight hours, based on an 8-week study period in summer. The sampling period was confined to 1 h after rising to time of sunset, eliminating those samples from participants who bypassed the request to take the nature pill "before dark." The data analysis ultimately included only those NEs that ended before sunset time on the NE date. These criteria led to the best model fit for linearity in the log-transformed data (**Table 3**). The decision to use sunset time as the cut point for data inclusion gains support from other research studies that did not detect a problematic point of downturn in diurnal amylase during the evening hours. For example, the latest time of day for sampling include 8 p.m. (Nater et al., 2007), 9 p.m. (Out et al., 2013), and (unspecified) bedtime (Karlamangla et al., 2013). Nonetheless, all of these results underscore the need to control for time of day when doing research where amylase is the stress marker.

The role of sunset time through the year on diurnal cycle of alpha-amylase needs formal investigation. At present, we know of only one other study, with rats, indicating an effect of sunset time on alpha-amylase. Bellavia et al. (1990) reported that the diurnal pattern of production disappeared when photoperiod changed to constant light or constant dark for 15 days. Based on our results, we hypothesize that time of year and latitude, both of which contribute to day length and sunset time, will adjust the temporal form of diurnal amylase production. It is particularly important to learn more about the role of day length variation in studies about nature restoration because evening often affords working people greater flexibility for self-care. New research on the after dark trajectory of amylase diurnal production is also of great interest because an after-dark nature pill affords the opportunity to investigate non-visual aspects of nature restoration, a critical but relatively unstudied aspect of our relationship with the environment (Franco et al., 2017).

Amylase Sensitivity to Physical Exertion

We were somewhat surprised that casual walking produced such a noticeable effect on salivary amylase production. In terms of this stress marker, the drop in amylase after a walking nature pill was small (4% per hour) and indistinguishable from the diurnal baseline. By contrast, under low exertion – sitting or sitting with some walking, the nature pill produced a 28% per hour drop in amylase after accounting for the diurnal baseline. In a literature review that focused on high intensity exercise, Koibuchi and Suzuki (2014) concluded that exercise upregulates salivary amylase. The few studies that involved low intensity exercise did not show amylase elevation: a 30-min light gymnastics program for the elderly and relaxed 20-min walks in either forest or urban settings by university students. In our experiments, the assumption that non-aerobic walking would not constitute a physical stressor was wrong.

In another experiment using self-report data on psychological response rather than physiological response, the impact of exercise intensity also showed up. Barton and Pretty (2010) evaluated the effect of green exercise (activity in the presence of nature) on subjective ratings of mood and self-esteem from over 1200 participants, each involved in one of 10 experiments carried out over a 6-year period in the United Kingdom. Estimates of dose–response relationships in terms of green exercise duration and intensity showed significant benefits to mental well-being after even short engagements with green exercise – as little as 5 min, with positive effects diminishing over duration periods up to a half day, then rising with durations up to a full day. Improvements to self-esteem and mood during their first duration period (less than an hour – a duration that is coincidental with that in our experiment) were greater for the lower intensity green exercise (e.g., walking) compared to more intense exercise (e.g., cycling).

Limitations and Potential

To develop a robust basis for prescribing a nature pill, more research is needed on the role of NE duration, frequency, and the perceived quality of the nature experienced (beyond the natural versus urban environment dichotomy) in the delivery of positive effects. Key among the challenges is the need for a large and diverse sample size because the diurnal form of cortisol and amylase production changes with age and stress level (Strahler et al., 2017), socioeconomic factors (Karlamangla et al., 2013), and lifestyle factors such as sleeping patterns (Van Lenten and Doane, 2016). A truly functional form of the nature pill prescription will emerge from testing a more diverse participant pool (gender, age, and lifestyle) from a diversity of settings (habitat types, both familiar and novel), and across seasons. The experimental approach described here can efficiently support the large sample size needed to accommodate these factors.

Researchers have discussed the difficulty with adherence in prescribed behavior testing (Olem et al., 2009; McCahon et al., 2015). In our experiment, we balanced stringency with adaptive adherence opportunities in order to get a realistic assessment of the value of NEs under normal circumstances. For example, the requirements to make time for repeated NEs with limitations on ingesting, social exchange, and aerobic exercise, etc., were balanced by the freedom choose when, where, and duration (beyond 10 min) of a NE. That said, the use of self-selected participants who were more likely to adhere to the parameters of the experiment could have biased the results if the benefits of nature are more readily gained by those who are willing to spend or enjoy spending their free time in this way. Future experiments would benefit from a participant group that showed the range of interest in NEs but were equally rewarded (e.g., money) for adherence regardless of natural inclination.

Our study had 36 participants, a sample size that is twice that of the median sample size in 18 studies on the same topic (see review by Kondo et al., 2018). However, our sample size for the number of nature pills with a saliva collection was not sufficient to fully investigate duration times at either end of the spectrum (i.e., under 10 min and over 30 min). Additional research is needed on this aspect of nature pill duration.

The usefulness of amylase in this study was reduced by confounding effects of physical exertion and time of sunset. These effects can be handled through experimental design and *post hoc* data cleaning. But why use amylase when cortisol is without these limitations? There is opportunity for efficient and cost-effective self-monitoring of amylase with technologies that are already in the marketplace. For example, amylase can be readily measured in the field using a phone app and an add-on sampling device that attaches to the phone (Zhang et al., 2015). Such devices are valuable for athletic training because exertion stress data (e.g., aerobic threshold) can be used to formulate an effective training plan (Akizuki et al., 2014). To be useful for tracking mental stress, however, it would appear that low physical exertion is required. To demonstrate the ability of their smart-phone-based potentiometric biosensor to test psychological status, Zhang et al. (2015) evaluated salivary amylase in sitting participants before and after exposure to images from the affective picture system (IAPS), known to induce positive and negative emotions. The outcome was in good agreement with a published report of the same test using traditional collection and sample analysis methods for amylase level.

Our experimental approach for assessing the restorative power of a NE offers an efficiency and clarity that can be used to better address questions about duration, frequency, attenuation, and the efficacious quality of the nature encountered, particularly in an urban setting (Bratman et al., 2012; Hunter and Askarinejad, 2015; Cox et al., 2017a; Frumkin et al., 2017). Answers to these questions will also support better-informed economic models and policy decisions aimed at containing personal, societal, and health care costs (Kardan et al., 2015; Wolf et al., 2015; Shanahan et al., 2016) and, ultimately, support the cultural uptake of more time outside/less time on-screen[4].

CONCLUSION

The methods for this adaptive management study of nature-based restoration break new ground in addressing some of the complexities of measuring an effective nature dose in the context of normal daily life. Our approach was empirically field tested in the service of measuring the relationship between the duration time of a NE and stress level using physiological biomarkers. The stress markers revealed that taking a nature pill reduces stress by 21%/h (salivary cortisol) and 28%/h (salivary amylase). When the duration of the NE is between 20 and 30 min, the gain in benefit is most efficient.

This work is novel in several ways.

(1) Results came from an experimental approach that can efficiently distinguish the contribution of a nature-based stress reduction from the concomitant diurnal change of a stress marker.
(2) The experimental design bypasses the need for participants to take multiple saliva samples throughout each testing day to establish a personal diurnal curve. Instead, one saliva collection (pre-NE) per sample date established a diurnal form of the stress markers that was comparable to the diurnal trajectory in other outdoor studies.
(3) Unlike previous studies, this one included repeated-measures testing of the same individuals over 2 months,

[4]https://www.apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2014/07/08/09/18/improving-health-and-wellness-through-access-to-nature

allowing us to capture the realism of changing psychological and physiological states and reactions to changing environmental context for each participant.

(4) The experimental format is unique for nature restoration research in its use of an adaptive management design. Participants had significant control in how they "medicated" themselves in terms of when, where, and length of a NE. This flexibility is essential for establishing and maintaining self-care behaviors in the face of responsibilities to others, lifestyle, and personal preference.

(5) The data analysis demonstrates how to quantify parameters of a nature prescription using a population approach for evaluation of nature exposure along a duration continuum set by participants.

The outcomes of our experiment are coherent with those of studies of stress biomarkers involving much greater control and much higher sample sizes. Moreover, the empirical results on stress reduction relative to the duration of a NE offer a validated starting point for healthcare practitioners prescribing a nature pill to those in their care. We think that our methodological approach for parameterizing a prescription (duration, frequency, and nature quality) for the nature pill is a tool that can be used by a field of study poised for new insights on the contributions of age, gender, seasonality, physical context, and cultural context to the effectiveness of nature exposure on well-being.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Institutional Review Board of the University of Michigan, IRB-Health Sciences and Behavioral Sciences (HSBS) committee, with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Institutional Review Board of the University of Michigan, Ann Arbor, MI, United States (IRB # HUM00089147). Regarding exemption status, the IRB committee has also determined that the study, as currently described, is now exempt from ongoing IRB review, per the following federal exemption category: research in which study activity is limited to analysis of identifiable data. For purposes of this research study, all research subject interactions and interventions have been completed and the data continue to contain subject identifiers or links. The research is not federally funded, regulated by the FDA, or conducted under a Certificate of Confidentiality.

AUTHOR CONTRIBUTIONS

MH made substantial contributions to the conception of the work, the experimental design, the acquisition of data, the analysis and interpretation of data, and drafting the manuscript and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. BG made substantial contributions to the analysis and interpretation of data and revising the manuscript critically for important intellectual content. SC made substantial contributions to the analysis of data and revising the manuscript critically for important intellectual content.

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REVIEW
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Experiences in Nature and Environmental Attitudes and Behaviors: Setting the Ground for Future Research

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There is empirical evidence suggesting a positive link between direct experiences in nature and people's environmental attitudes (EA) and behaviors (EB). This has led researchers to encourage more frequent contact with nature, especially during childhood, as a way of increasing pro-environmentalism (i.e., pro-EA and pro-EB). However, the association between experiences in nature and EA/EB is complex, and specific guidelines for people's everyday contact with nature cannot be provided. This article offers an overview of the research conducted until know about the relation between experiences in nature and pro-environmentalism, and opens up new inquiries for future research. We begin with an introduction to people's current tendency toward an alienation from the natural world and set out the objectives of the article. It is followed by three main sections. The first one reports on what experiences in nature refer to, how and where they occur. The second section describes the different approaches used to investigate and interpret the experiences in nature-EA and EB relation. The last section provides suggestions for future research. We close by making some final remarks about the importance of (re)stablishing a greater interaction with nature for people's pro-EA and EB.

Keywords: biophilia, connection to nature, ecological behavior, environmental identity, experiences of nature, nature-based recreation, nature exposure, outdoor recreation

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INTRODUCTION

Experiences in nature are associated with several benefits, such as recovery of cognitive resources (Hartig et al., 2014), increased pro-environmental attitudes (EA) (Chawla and Derr, 2012) and behaviors (EB) (Evans et al., 2018), more frequent physical activity (Schaefer et al., 2014) and increases pro-social orientation (Joye and Bolderdijk, 2014). In spite of these positive effects of people's contact with nature, there is mounting evidence indicating that people's direct contact with nature is diminishing (Zaradic et al., 2009; Soga and Gaston, 2016). Several reasons have been suggested for this growing alienation from the natural world, including increased urbanization rates, more frequent use of new technologies for entertainment, and the perception of nearby natural places as insecure (Clements, 2004; Tandon et al., 2012; Soga and Gaston, 2016;

Larson et al., 2018a). Researchers have warned that this lack of experiences in nature may have negative consequences for people's pro-environmentalism (i.e., their pro-EA and pro-EB) (Soga and Gaston, 2016; Evans et al., 2018; Rosa et al., 2018), which could lead to detrimental consequences for the environment (Evans, 2019). As a result, there has been a proliferation of initiatives (e.g., no child left inside) and publications (e.g., Louv, 2008) targeted at the general public with the aim of encouraging a more frequent contact with nature from early childhood. Yet, is the link between experiences in nature and pro-environmentalism as well-stabilised as the studies above suggest? Based on what is currently known about experiences in nature and pro-environmentalism, the main goal of this article is to outline a number of issues for future research on this area. To do this, we first review and synthetize the different approaches from which the relation between experiences in nature and pro-environmentalism has been studied. In our review, EA are seen as a "collection of beliefs, affect, and behavioral intentions a person holds regarding environmentally related activities or issues" (Schultz et al., 2005, 458). This definition is quite broad and, as such, we consider in our review studies evaluating people's ecological beliefs (Van Liere and Noe, 1981), connectedness to nature (Mayer and Frantz, 2004), place attachment (Hou et al., 2005), biophilia (Zhang et al., 2014), and willingness to engage on EB (Larson et al., 2018b).

Experiences in nature are positively associated with stronger pro-environmentalism, such as emotional affinity toward nature (Kals et al., 1999), willingness to conserve biodiversity (Soga et al., 2016), willingness to pay for the conservation of urban green spaces (Lo and Jim, 2010), and pro-EB (Evans et al., 2018). Overall, researchers have found a positive link between EA and EB (Bamberg and Möser, 2007). This is in line with the Theory of Planned Behavior (Ajzen, 2011), and the Value-Belief-Norm-Theory (Stern et al., 1999), and have been supported empirically (e.g., Dunlap et al., 2000; Markle, 2013). As a general trend, the relation between experiences in nature and EB is mediated by EA (Larson et al., 2011; Pensini et al., 2016; Otto and Pensini, 2017; Rosa et al., 2018). Several ideas have been offered to explain why experiences in nature positively influence EB. These explanations include increased biocentric values (Larson et al., 2011), connectedness to nature (Otto and Pensini, 2017), and beliefs about the New Environmental Paradigm (Collado et al., 2013), a stronger sense of place attachment (Lawrence, 2012), increased positive emotions (Mayer et al., 2009) and renewal of depleted attentional capabilities (i.e., psychological restoration) (Byrka et al., 2010; Collado and Corraliza, 2015; Wyles et al., 2017), and a stronger sense of morality toward the environment (Hahn and Garrett, 2017).

In spite of the positive associations between experiences in nature and pro-environmentalism reported in previous studies, this relation is a complex one (Clayton et al., 2017). This complexity has, to our knowledge, been overlooked. Our departure point is an overview of the research findings in this area, distinguishing six different approaches used to examine the relation between people's experiences in nature and pro-environmentalism. Then, we address what we consider to be more urgent in terms of future research. The article has been organized in three main sections describing: (a) experiences in nature: how and where they occur, (b) approaches used to investigate and interpret the link between experiences in nature and pro-environmentalism, and (c) future research.

EXPERIENCES IN NATURE: HOW AND WHERE THEY OCCUR

By experiences in nature we refer to time spent in natural areas, including wild natural areas, such as forests, but also nearby natural environments, like urban parks, gardens, and vacant lots (Chawla and Derr, 2012; Keniger et al., 2013; Rupprecht et al., 2016). Several authors have defined experiences in nature by focusing on specific aspects of the person–nature interaction. For instance, Keniger et al. (2013) considered the motivation for people's interactions with nature (i.e., intentional or non-intentional). According to these authors, there are two different types of experiences in nature. First, individuals can have incidental contact with nature (i.e., experiencing nature as a by-product of another activity, such as walking the dog). Second, experiences in nature can be direct and intentional, when people have the intention to be in direct contact with nature. Direct and intentional contact with nature in an esthetically pleasing environment is thought to be the best way for people to connect with nature, as it involves the use of diverse senses (Lumber et al., 2017; Giusti et al., 2018). In line with this, Mayer et al. (2009) found a higher increase in connectedness to nature after people had a direct experience in nature compared to an indirect contact with nature through a video.

Another way of defining people's experiences in nature is by focusing on the type of activity conducted in the natural setting [see Berns and Simpson (2009) for a review]. The authors distinguish three types of experiences in nature: consumptive, mechanized, and appreciative. According to Berns and Simpson (2009), consumptive activities in nature refer to taking something from the environment for your own use (e.g., fishing, hunting). In turn, mechanized activities in nature are activities in which mechanized equipment is used to interact with nature (e.g., off road vehicles). Last, appreciative activities in nature relate to enjoying the natural environment (almost) without altering it through self-propelled non-mechanized activities (e.g., surfing, birdwatching, hiking). Research evidence suggests that appreciative experiences in nature are the ones more strongly linked to pro-environmentalism.

Clayton et al. (2017) went a step further in defining people's experiences in nature. The authors considered the social context in which experiences in nature take place. In their view, experiences in nature can be self-directed, when the person interacts freely with the environment or other-directed, when the person interacts with the natural environment following someone else's guidance (e.g., tour guide). In addition, interactions with nature can be solitary experiences or they can happen in the company of others and, at the same time, they can provide positive or negative emotional responses (Clayton et al., 2017).

APPROACHES USED TO INVESTIGATE AND INTERPRET THE LINK BETWEEN EXPERIENCES IN NATURE AND PRO-ENVIRONMENTALISM

According to our review of the research findings in this area, we can distinguish six main research approaches to examine the relation between experiences in nature and pro-environmentalism. Below, we describe the main findings derived from each of these approaches. These are summarized in **Table 1**.

First, the relation between people's experiences in nature and pro-environmentalism has been examined from research in the area of significant life experience (SLE). According to SLE studies, childhood positive experiences in nature are the main factor predicting pro-environmentalism later in life (Tanner, 1980; Chawla, 1999; Corcoran, 1999; Chawla and Derr, 2012). These studies are mainly qualitative and retrospective. For instance, Tanner (1980) evaluated the experiences that 45 environmental activists recalled as being more important for their decision of working as environmental conservationists. According to Tanner's (1980) findings, experiences in nature as a child were the main predictor of their choice. Recently, Cagle (2018) conducted a retrospective investigation about experiences in nature over time. Participants were 12 environmentally committed faculty members of Duke University (United States). Her results supported previous findings, indicating that childhood experiences in nature were important for the formation of a bond with nature that lasts until adulthood. In line with these results, Gray and Pigott (2018) found that people who participated in a 2-year nature-immersive activity when they were about 15 years old recalled that experience, 30 years later, as a motivating factor to choose a career related to conservation, wilderness guiding, and environmental education.

A second research approach involves the evaluation of the effect that different types of activities in nature may have in pro-environmentalism. For instance, Knopp and Tyger (1973) found that individuals engaged in an appreciative activity (ski touring) held stronger EA than those involved in a mechanized activity (snowmobiling). Similarly, Wolsko and Lindberg (2013) found a positive link between participating in appreciative activities and connectedness to nature, and a negative association between participating in motorized activities and connectedness to nature. Due the cross-sectional design of these studies, it is not possible to establish whether individuals with strong EA prefer appreciative activities as argued by Bjerke et al. (2006), or if participating in appreciative activities improves individuals' EA, as argued by Dunlap and Hefferman (1975). Yet, both perspectives could be correct (Jackson, 1986). In concordance with Dunlap and Hefferman's (1975) perspective, Wyles et al. (2017) conducted an experimental study analyzing the effect of three appreciative activities (e.g., coastal walking) in individuals' intention to engage on responsible environmental behaviors and found that the three activities increased participants' intention to engage in these behaviors in a similar way.

TABLE 1 | Description of the approaches applied to the study of the relation between experiences in nature and EA and EB.

Approach	Brief description	Main insights	Example of classical studies
1. Significant life experience (SLE)	Studies analyzing the reasons why environmental activists devoted their lives to taking care of the environment. Childhood experiences in nature have been identified as a main driver for adulthood pro-environmentalism.	SLE literature shows that it is important to consider lifetime experiences with nature in order to understand current EA and EB.	Tanner, 1980
2. Comparison between nature-based recreationists EA and EB	Studies analyzing if individuals involved in different nature-based recreational activities have distinct EA and EB. For example, comparing EA and EB of hunters with those of birdwatchers.	These studies indicate that the type of interaction with nature (e.g., consumptive vs. appreciative) needs to be considered when analyzing the link between interactions with nature and pro-environmentalism.	Dunlap and Hefferman, 1975
3. Specialization	Studies analyzing whether differences in pro-environmentalism are linked to nature-based recreationist specialization (e.g., experience and technical skills a person has on a recreational activity).	This literature provides insights about the relevance of individuals' specialization on a nature-based recreational activity to the understanding of their EA and EB.	Bryan, 1977
4. Interactions with nature influences pro-environmentalism	Studies analyzing whether interactions with nature can increase people's pro-environmentalism.	Positive direct experiences in nature are linked to an increase in pro-environmentalism.	Mayer et al., 2009
5. EA influence interactions with nature	Studies analyzing whether people's EA can influence their pattern of interactions with nature.	This literature suggests that EA may be a driver for interactions with nature.	Lin et al., 2014
6. The perceived benefits of interactions with nature as predictors of pro-environmentalism	Studies analyzing if the perceived benefits of interactions with nature (e.g., restoration, pleasure) are associated with people's pro-environmentalism.	Studies on this approach suggest that people EA and EB may change when they realize the benefits of nature to their lives.	Hartig et al., 2001

A third line of study consists on analyzing the possible differences on nature-based recreationists' EA and EB based on their specialization on a specific nature-based activity. Specialization is generally considered a multidimensional concept formed by behavioral, affective, and cognitive factors (Scott and Shafer, 2001; Garlock and Lorenzen, 2017; Kim and Song, 2017). It is commonly assessed by a series of factors such as recreationists' experience in a nature-based activity, the importance of this activity for the individual's lifestyle, the technical skills required by this specific activity, and the expenses of the activity (McFarlane and Boxall, 1996; Scott and Shafer, 2001; Garlock and Lorenzen, 2017; Kim and Song, 2017). In comparison to less specialized recreationists, the more specialized ones are expected to be more experienced, to show greater mastery of the techniques associated with the leisure activity, to spend more money on the activity, and to perceived the activity as more relevant for his/her lifestyle (Scott and Shafer, 2001). Previous studies have investigated if more specialized nature-based recreationists such as birdwatchers (McFarlane and Boxall, 1996), anglers (Garlock and Lorenzen, 2017), and boaters (Jett et al., 2009) hold distinct EA and EB than less specialized nature-based recreationists. One hypothesis is that as a person specializes in an activity, pro-EA and engagement in pro-EB can increase (Bryan, 1977; McFarlane and Boxall, 1996). This may occur because more specialized recreationists perceive the recreational activity they practice as more relevant for them than less specialized recreationists, and these activities depend upon natural resources (Bryan, 1977). Hence, more specialized recreationists may hold greater concern for the maintenance of the natural resources where the activity is conducted than less specialized recreationists. Literature findings generally support this hypothesis, with more specialized individuals reporting higher levels of environmental concern and greater engagement in pro-environmental behaviors (Thapa et al., 2006).

A fourth approach in the study of people's experiences in nature and pro-environmentalism involves the prediction that direct experiences in natural environments foster pro-EA and EB. In the last years, several interventions have showed that experiences in nature can foster children's (Crawford et al., 2017; Schneider and Schaal, 2017) and adults' connectedness to nature (Lumber et al., 2017; Richardson and McEwan, 2018), an important predictor of pro-EB (Tam, 2013; Frantz and Mayer, 2014). For example, Barton et al. (2016) found an increase in adolescents' connectedness to nature after a wildness expedition. Evans et al. (2018) conducted a longitudinal study in which they found, after controlling for possible confounding variables (e.g., child environmental behavior), that one of the main predictors of young adults' EB was time spent outdoors during childhood. Considering these results, it does not come as a surprise that direct contact with nature has been seen as a predictor of pro-environmentalism in the environmental education domain, with several environmental education projects focusing on nature experiences as a way of promoting EA and EB (Evans et al., 2007; Duerden and Witt, 2010). For example, De Dominicis et al. (2017) found an increase on place attachment, pro-EA, and self-reported pro-EB after a nature-based environmental education program. Similarly, Collado et al. (2013) found that time spent in nature-based summer camps, with and without environmental education within their daily program, had positive effects on EA and EB.

The fifth approach in the study of the link between experiences in nature and pro-environmentalism relates to the influence of EA on the way people interact with nature. Empirical evidence supports that EA motivate people to interact with nature (Lin et al., 2014; Soga and Gaston, 2016; Lin et al., 2017) and influences their choice for nature-based activities (Bjerke et al., 2006; Thapa, 2010; Marques et al., 2017). For example, Lin et al. (2014) found that people who felt more connected to nature were more likely to visit parks and to spend more time on their private yard than people who felt less connected to nature. Similarly, Bjerke et al. (2006) noted that people's environmental beliefs were associated to their preference for nature-based activities. They found that individuals with stronger environmental beliefs reported higher preference for activities, like scenery photographing and mountaineering, compared to individuals with weaker environmental beliefs.

The last approach involves the perceived benefits of experiences in nature and how these perceptions lead to pro-environmentalism (Hartig et al., 2007; Byrka et al., 2010; Lee, 2011; Collado and Corraliza, 2015; Lee and Jan, 2018; Whitburn et al., 2018). Natural settings are often perceived as places linked to wellbeing (Carrus et al., 2015), where attentional resources can be recovered (Carrus et al., 2017) and energy can be regained (Ryan et al., 2010). For instance, Lee (2011) reported that individuals' satisfactions with time spent in nature was related to their conservation commitment and pro-EB. Similarly, Collado and Corraliza (2015) found that children who reported higher restoration after spending time in nature held stronger pro-EA which, in turn, led to conducting pro-EB more frequently. Hartig et al. (2001, 2007) reached similar conclusions with adult samples. These results suggest that the link between experiences in nature and pro-environmentalism can be explained, at least partly, by the benefits people perceive they obtain from time spent in nature.

Overall, the six approaches described suggest that there is a positive relation between experiences in nature and pro-environmentalism. However, as previously indicated, this relation is a complex one (Clayton et al., 2017) and contradictory results have been found in the literature. For example, considering SLE, Howell and Allen (2016) concluded that nature experiences during childhood did not have a major formative influence on 85 people involved in climate change education and mitigation. Their findings suggest that for their participants, factors different from nature experiences during childhood, such as altruistic concerns about climate change, may play a major role in the way they behave toward the environment during adulthood. Also, one would expect that spending time in natural areas while being part of an EE program provides an additional benefit to pro-environmentalism due to the relevant formal environmental information that participants received through EE programs (Kuo et al., 2019). However, this is not always the case. In fact, EE programs could constrain individuals' willingness to experience nature freely, and the provision of environmental knowledge may be seen as boring (Duerden and Witt, 2010;

Collado et al., 2013). Thus, environmental educators have made an effort to develop ways of learning in nature while keeping the experience as fun as possible (Crawford et al., 2017; Schaal et al., 2018).

Contradictory results were also found when considering how different types of experiences in nature were associated to EB (Cooper et al., 2015). The authors expected appreciative activities to be more strongly associated to pro-EB than consumptive activities. However, they found that individuals participating regularly in both hunting and birdwatching (hunter–birdwatcher) were more likely to engage in specific conservation behaviors than individuals participating regularly either in hunting (consumptive) or birdwatching (appreciative). Regarding specialization, Jett et al. (2009) found a negative association between the level of specialization of boaters and their attitudes related to marine conservation. According to their results, more specialized individuals were less likely to agree that, regardless of regulations, manatees deserve to be protected and that reducing vessel speed is an effective strategy for marine conservation. Jett et al. (2009) believe that the reason behind these results is the aversion of more specialized individuals to limitations to their leisure pursuit. The benefits people attribute to time spent in nature (e.g., psychological restoration, well-being) can be moderated by people's EA (Davis and Gatersleben, 2013; Knez and Eliasson, 2017; Craig et al., 2018). In line with this idea, Knez and Eliasson (2017) found that people feel greater well-being when visiting outdoor settings if they held stronger attachment to these settings. Likewise, Craig et al. (2018) noted that people more connected to nature perceive nature experiences as more pleasurable than those whose connection to nature is lower.

To sum up what we can learn from these approaches, experiences in nature during childhood and adulthood are positively linked to pro-environmentalism (Tanner, 1980; Crawford et al., 2017; Lumber et al., 2017; Rosa et al., 2018). The effect of nature experiences on people's EA and EB depends on several factors, such as type of experience in nature (Knopp and Tyger, 1973), perceived benefits of these experiences (Hartig et al., 2001; Carrus et al., 2017), and the person's level of specialization in a certain activity (Bryan, 1977). However, the results found until now are mixed, indicating that the relation between experiences in nature, EA, and EB is not simple, and that there is a need for more nuanced research on the topic. Following, we suggest what we consider to be the most urgent lines of research.

FUTURE RESEARCH

By now we have reviewed the diverse approaches used to investigate and interpret the relation between experiences in nature and EA and EB. We acknowledge the scientific advances done on this topic during the last four decades. Yet, the relation between experiences in nature and pro-environmentalism is, in our opinion, not completely understood. There are some knowledge gaps, contradictory results, and methodological issues that preclude us to firmly claim how and when experiences in nature lead to an increase in pro-environmentalism. Below, we highlight six areas for further investigation.

First, researchers should acknowledge the possibility of a cyclical relation between experiences in nature and pro-environmentalism. There is theoretical and empirical support for two perspectives: (1) experiences in nature enhance EA, leading to EB; and (2) EA can influence people's patterns of interaction with nature. Whereas several experiments have supported the first perspective (Mayer et al., 2009; Crawford et al., 2017; Lumber et al., 2017), the second one has not been, to our knowledge, experimentally proven. The experimental examination of the second perspective as well as of the possible cyclical relation between experiences in nature and pro-environmentalism awaits future research.

Second, a clear definition of what researchers understand by experiences in nature is still missing. Experiences in nature can have many different forms. For instance, they can be direct and incidental (e.g., experiencing nature while walking the dog), direct and intentional (e.g., surfing), alone or with company (e.g., family, friends), and during work or leisure time. Moreover, even if a definition is given (e.g., Collado and Sorrel, 2019), it is generally broad, and focused on contact with green natural elements. The possible effects that exposure to different types of natural environments have in pro-environmentalism, including water bodies (e.g., oceans, lakes, rivers), settings with different geological and orographic characteristics (e.g., mountain area versus a plain natural setting), and different meteorological conditions remain underexplored. For instance, Talebpour (2018) found that fifth-grade students who participated in a nature immersive program during inclement weather had a decrease in their connectedness to nature compared to before the immersion, whereas students who had the same nature experience with better weather conditions had an increase in connectedness to nature after the immersive program. Future studies should describe in detail how experiences in nature take place, including the meteorological conditions as well as the natural elements participants might encounter. The possible positive impact of direct and visual contact with non-human animals on people's pro-environmentalism also needs further consideration [see Young et al. (2018) for a review]. Finally, the word *nature* can have different meanings for people from different cultures (Wohlwill, 1983; Collado et al., 2016; Profice, 2018) and as such the definition of experiences in nature should take into account participants' cultural background. For instance, some people may consider humans are part of nature while others may not (Wohlwill, 1983; Mayer and Frantz, 2004) and differences in the esthetic perception of nature have consequences for biodiversity protection (Williams and Cary, 2002). Given that the meaning of nature is influenced by our social context (Wohlwill, 1983), researchers should pay special attention to people's conceptions of nature in cross-cultural research.

Third, a clear definition of experiences in nature should be accompanied by a valid measure of frequency of contact with nature. This would facilitate the comparison of results among studies as well as the generalization of findings. Whereas there are likely hundreds of published studies on the topic, to our knowledge, a validated and reliable measure of frequency of contact with nature has not been developed. Researchers generally develop or adapt *ad hoc* measures for their own studies. Experts on the appraisal of measures have argued that the use of non-validated and reliable measures may be a waste of resources and unethical (Mokkink et al., 2018). In light of the research lines described above, researchers may need to think of different measures for different population groups (e.g., children and adults), as well as to be used in different contexts in which experiences in nature are likely to differ (e.g., developed versus developing countries).

Forth, the type of activities in nature leading to pro-environmentalism are fairly unknown, as well as the social context in which these activities occur. We know from previous studies that positive, appreciative experiences in nature may play a stronger role in the formation of pro-environmentalism than consumptive and mechanized activities but we know little about the different effect that different appreciative activities may have (Wyles et al., 2017). For instance, would going for a walk in nature have the same effect as sitting and relaxing in a park? In line with this idea, Giusti et al. (2018) developed a framework to understand how children connect with nature. Their results showed that some forms of experiencing nature (those that engaged children's senses were children-driven and thought provoking) were more effective to connect children with nature than others (e.g., structured activities). And, would the link between experiences in nature and pro-environmentalism be stronger when these experiences take place alone or when they take place with the company of close ones? Retrospective studies have shown that adults recall positive experiences in nature during childhood in the company of others as the main driver of their current pro-environmentalism (Chawla and Derr, 2012). Yet, when in need of psychological restoration, adults prefer to spend time alone in a natural environment (Staats and Hartig, 2004). Whether there is a difference between spending time in nature alone or with friends in terms of pro-environmentalism and the possible effect of the foreseeable change of children's social group as they grow up deserves further exploration. Future longitudinal research should focus on how experiences in nature change through the lifespan (Cagle, 2018) and how these different interactions in the natural environment lead to pro-environmentalism.

Fifth, participants' sociodemographic characteristics should be considered in the experiences in nature–pro-environmentalism relation. These include age, gender, education, place of residence (urban vs. rural), and political ideology [see Gifford and Nilsson (2014) for a review]. Younger people, women, and liberals tend to be more open to improve their EA than older people, men, and conservatives (Heberlein, 2012; Gifford and Nilsson, 2014). Thus, experiences in nature may have a greater impact on young women with liberal ideas. Given that individuals with a lower educational level generally hold weaker EA (Gifford and Nilsson, 2014), they may benefit the most from experiences in nature. Also, people living in rural areas tend to have more frequent contact with nature (Hinds and Sparks, 2008; Muslim et al., 2017) than those living in cities. Rural residents also differ from urban ones in their preference for different types of landscapes (Williams and Cary, 2002) and their daily type of contact with nature (Collado et al., 2015) which can influence the outcomes of experiences in nature. For example, Bixler et al. (1994) found that urban residents tend to express fear and discomfort when spending time in wildland areas. Williams and Cary (2002) found that urban residents held a stronger preference for more grazed woodland landscapes than rural residents do. Considering children, Collado et al. (2015) concluded that children living in mountain rural areas experienced nature more freely than those living in cities. Even though these studies suggest that the effects of experiences in nature on people's pro-environmentalism may be moderated by sociodemographic characteristics, only a few studies have included them in their studies (e.g., Mayer et al., 2009; Larson et al., 2011; Collado et al., 2015; Rosa and Profice, 2018). These individual factors should be considered in future research about the experiences in nature–pro-environmentalism link.

Sixth, most of the studies revised through this paper are cross-sectional and their samples non-representative. This limits causal inferences and the generalization of the results to larger populations. Also, most of the studies investigating EB and experiences in nature assessed self-report (vs. observed) behaviors. This could be an issue because self-reports can be influenced by diverse biases such as social desirability, mood state, and consistency motif (Podsakoff et al., 2003). Hence, self-reported behaviors may not correspond to observable behaviors (Kormos and Gifford, 2014). Moreover, most of studies investigating the association between childhood experiences in nature and adults' pro-environmentalism relied solely on adults' self-reported experiences in nature during childhood (e.g., Wells and Lekies, 2006; Larson et al., 2011; Pensini et al., 2016; Asah et al., 2018; Rosa et al., 2018) with few exceptions (Liddicoat and Krasny, 2014; Evans et al., 2018; Gray and Pigott, 2018). Adults' self-reports of childhood experiences in nature could be imprecise and may be influenced by their actual EA (Kals et al., 1999; Wells and Lekies, 2006). Therefore, there is a need for representative surveys, more reliable measures of EB and experiences in nature, and longitudinal studies estimating experiences in nature and EA and EB at different time-points.

FINAL REMARKS

There is plenty of evidence supporting the positive link between experiences in nature, EA, and EB. We agree with previous researchers encouraging a more frequent exposure to nature both for adults and children, as this can have positive effects both on pro-environmentalism (Crawford et al., 2017; Lumber et al., 2017) and health (Hartig et al., 2014; Kuo et al., 2019).

However, the complexity of the positive association between experiences in nature and pro-environmentalism urges future studies with which researchers can provide plausible explanations of this positive link, as well as offer more specific guidelines for translating empirical studies into every day practices. For example, future studies can help to shed some light about which are the best type experiences in nature to improve pro-environmentalism (e.g., Giusti et al., 2018), and ways to increase people's contact with nature within their daily life (e.g., Soga et al., 2018).

AUTHOR CONTRIBUTIONS

CR and SC conceived the ideas included in the manuscript and wrote the manuscript.

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SYSTEMATIC REVIEW
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Immersive Nature-Experiences as Health Promotion Interventions for Healthy, Vulnerable, and Sick Populations? A Systematic Review and Appraisal of Controlled Studies

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In this systematic review, we summarized and evaluated the evidence for effects of, and associations between, immersive nature-experience on mental, physical, and social health promotion outcomes. Immersive nature-experience was operationalized as non-competitive activities, both sedentary and active, occurring in natural environments removed from everyday environments. We defined health according to the World Health Organization's holistic and positive definition of health and included steady-state, intermediate, and health promotion outcomes. An electronic search was performed for Danish, English, German, Norwegian, and Swedish articles published between January 2004 and May 2017. Manual approaches, e.g., bibliographies from experts, supplemented the literature search. Data were extracted from 461 publications that met the inclusion criteria. To assess the status and quality of the evidence for health promotion effects of immersive nature-experience, we focused on the subset of studies based on controlled designs (n = 133). Outcome level quality of the evidence was assessed narratively. Interventions most often involved adventure-based activities, short-termed walking, and seated relaxation in natural environments. We found positive effects on a range of health promotion outcomes grouped under psychological wellbeing (n = 97; ≈55% positive; ≈13% mixed; ≈29% non-significant; 2% negative); psychosocial function (n = 67; ≈61% positive; ≈9% mixed; ≈30% non-significant); psychophysiological stress response (n = 50; ≈58% positive; ≈18% mixed; ≈24% non-significant), and cognitive performance (n = 36; ≈58% positive; ≈6% mixed; ≈33% non-significant; 3% negative); and social skills and relationships (n = 34; ≈70% positive; ≈7% mixed; ≈22% non-significant). Findings related to outcomes categorized under physical health, e.g., risk of cardiovascular disease, were less consistent (n = 51; ≈37% positive; ≈28% mixed; ≈35% non-significant). Across the types of interventions and outcomes, the quality of the evidence was deemed low and occasionally moderate. In the review, we identify, discuss, and present possible solutions to four core methodological challenges associated with investigating immersive nature-experience and health outcomes: (1) intervention and program complexity; (2) feasibility and desirability of randomization; (3) blinding of participants and researchers; and (4) transferability and generalizability. The results of the review have been published as a popular-scientific report and a scientific research overview, both in Danish language.

Keywords: ***friluftsliv*** **(outdoor life), green exercise, green space, therapy, social ecology**

INTRODUCTION

Nature may be an affordable, upstream health promotion intervention (Maller et al., 2006) and is widely considered to enhance mental, physical, and social health (Hartig et al., 2011, 2014; Twohig-Bennett and Jones, 2018). However, there are countless ways, situations, and contexts in which nature may be encountered, visited, or used, which in turn may lead to varying health outcomes. While reviews have synthesized the wealth of predominantly correlational literature exploring nature contact and benefits for health (Bowler et al., 2010; Bratman et al., 2012; Hartig et al., 2014; Twohig-Bennett and Jones, 2018), the evidence is both diverse and dispersed. In agreement with Tillmann et al. (2018), we argue that a distinction between types of nature interaction is needed when assessing the evidence, and that existing reviews concerning nature and health have tended to compile interventions that are highly heterogenous (e.g., Twohig-Bennett and Jones, 2018). This approach involves a risk of obscuring the conditions under which contact with nature may or may not promote health outcomes. The consequences are simplified conclusions, reduced interpretational value, and potentially inappropriate health promotion recommendations.

Indicatively, Tillmann et al. (2018) found that that the ratio of positive to non-significant findings varied across three types of nature contact: exposure, i.e., direct and passive or non-specified encounters with natural environments and elements; accessibility, i.e., the likelihood of encountering or interacting with nature; and engagement, i.e., direct, intentional and sustained contact with nature. Exposure to nature and natural elements was most consistently associated with benefits for child and adolescent mental health, whereas accessibility to greenspace and direct engagement with nature provided more mixed results. The difference between the types of contact with nature could be caused by method-related issues or actual differences in achieved outcomes. For example, it is possible that there is a more widespread use of rigorously controlled designs and experimental conditions for exposure-type studies than for accessibility- and engagement-type studies. In this is the case, a focused effort to identify method weaknesses and to improve the quality of the research with consideration and adaptation to the type of nature contact is warranted. However, it is also possible that passive exposure to nature more often provides beneficial outcomes than direct engagement or accessibility to greenspace. This suggests that under some conditions or during specific activities, contact with nature is more likely to have health promoting outcomes than others. This highlights a need for an increased awareness to the context and type of activity involved with nature contact and the circumstances under which positive health promotion outcomes are obtained.

In this systematic review, we focused on the Scandinavian tradition of *friluftsliv*, which includes concepts such as "outdoor life," "outdoor recreation and education," or "adventure recreation and education," but with an emphasis on achieving a closeness to nature during the activity (Gelter, 2000; Sandell, 2003; Bentsen et al., 2009a). While the tradition is considered to be philosophically rooted in an industrialized, Scandinavian setting, activities in nature which encourage the feeling of being away from everyday life and immersion in the experience is practiced more widely (Gelter, 2000; Sandell, 2003; Bentsen et al., 2009a). These criteria are theorized to be fundamental to, for example, restorative experiences according to the Attention Restoration Theory (Kaplan, 1995) which has inspired much research, in both natural and manmade environments, outside of Scandinavia. However, existing reviews of *friluftsliv,* henceforth termed "immersive nature-experience," were mainly oriented toward Scandinavian practice and published in Scandinavian languages (Sandell, 2004; Schantz and Silvander, 2004). Although highly informative, these reviews were based on narrative identification, quality appraisal, and syntheses of the literature. From a medical, best-evidence paradigm point of view, the quality of the evidence was of low quality (Sandell, 2004; Schantz and Silvander, 2004). In these reviews, the research field anno 2004 was described as vast and interdisciplinary, dominated by qualitative and quantitative, correlational research. Therefore, the aim of this systematic review was to provide an updated, comprehensive overview of the existing research literature about the effects of immersive nature-experience and both mental, physical, and social health promotion outcomes.

Three main research questions frame this systematic review: (1) What types of immersive nature-experience and (2) health outcomes have been investigated, and (3) how do different types of immersive nature-experience influence or associate with mental, physical, and social health promotion outcomes.

We did not consider it meaningful or possible to evaluate the participants' acute and individual experience of being away or closeness to nature in the identified studies. Therefore, we operationalized some, perhaps arbitrary, conditions under which the nature experience should take place for the nature experience to be considered immersive: Inspired by Bentsen et al. (2009a), immersive nature-experience was operationalized as non-competitive activities, both sedentary and active, occurring in public natural environments removed from everyday environments. This, for example, did not include activities in sports fields with greenery, competitive sports in natural environments or transport to and from work or school through natural environments. While private gardens may promote health and afford activities in which individuals may immerse themselves in as well as experience a sense of closeness with nature, they are not removed from everyday life settings. Being away is a central experiential element of the type of immersive nature-experience under review, and we therefore excluded garden-based activities unless they occurred in settings removed from the participants' day-to-day life. All motorized activities in natural environments were excluded. We argue that a strength of this approach involves including nature-based interventions and programs that are more comparable in terms of content, e.g., activities and experiential character of the nature contact, situation, e.g., deliberate visits to nature, and activation of pathways, e.g., direct, multisensory contact with nature, to improved health (Kuo, 2015). To differentiate between contexts and situations of the immersive nature-experience in relation to health promotion outcomes, we divided the individual studies in three rough categories, namely recreation, health and social, and education. These are described in more detail in the methods section.

We defined health according to the World Health Organization's holistic and positive definition of health. Health promotion denotes the process of providing structures and empowering people to exert control over the determinants of health and risk factors (Nutbeam, 1998; Marmot, 2005). In other words, health promotion includes actions directed toward supporting active and healthy living and facilitating supportive environments (Nutbeam, 1998). Inspired by the outcome classification by Nutbeam (1998), we included health and social outcomes, e.g., quality of life and health status, but also proximal outcomes that influence health outcomes, i.e., intermediate health outcomes and health promotion outcomes. Intermediate health outcomes represent the determinants of health outcomes, e.g., lifestyle choices and actions. Health promotion outcomes reflect modulations of those personal, social and environmental factors which are means to improving people's control, e.g., improved health literacy, and thereby changing the determinants of health (intermediate health outcomes). Health literacy could, for example, be specified as physical literacy, which is defined as a person's capacities and attitude for engagement in physical activities (Edwards et al., 2018). In other words, this review covers not only narrowly defined health outcomes, such as functional independence or physical and mental health status, but also actions, e.g., physical activity (PA) and diet, and perceptions, e.g., self-concept and health literacy, that are involved in the process of health promotion. The focus of this review will be individual-oriented outcomes, not environmental or community level outcomes, although these are relevant in evaluations of health promotion interventions more broadly. While we maintain an analytical distinction between mental, physical, and social health promotion outcomes for communicative purposes, these are highly interdependent and developments in one outcome is likely to influence others.

The results of the literature search have previously been published as a popular-scientific report (Mygind et al., 2018a) and a scientific research overview (Mygind et al., 2018b), both in Danish language.

METHODS

The systematic review was inspired by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009) (for PRISMA checklist, please see **Supplementary Material A**). The review protocol can be accessed on the PROSPERO register of systematic reviews (ID: CRD42017057988)[1].

Eligibility Criteria

Publications were included if reporting on health promotion outcomes of immersive nature-experience (please see the introduction for the definition of immersive nature-experience and health promotion outcomes). We applied no restrictions pertaining to quality of the studies or population characteristics. To assess the status of the evidence concerning effects of the interventions, we focused our analysis on the subset of studies that included a control group. Since little research based on randomized trials was found, we included non-randomized controlled research with attention to the biases involved with this type of research.

We included existing reviews when all included studies investigated immersive nature-experience and health. In some cases, reviews of exposure to nature more broadly were included if it was possible to extract findings related to immersive nature-experience specifically (e.g., Haluza et al., 2014). We included studies that had been published in Danish, English, German, Norwegian, and Swedish language between January 2004 and May 2017. The latter of these criteria was chosen to extend the knowledge from previous reviews about immersive nature-experience and health, which included studies published before 2004 (Sandell, 2004; Schantz and Silvander, 2004).

Information Sources

Six electronic databases were searched using a generic search string that was adapted to the individual electronic databases (for the generic search string, see **Supplementary Material B**). These included Dissertation Abstracts, ERIC, PsycINFO, Scopus, SPORTDiscus, and Web of Science. We obtained additional literature on selected websites, through contributions from experts and by searching the reference lists in identified relevant publications.

Study Selection

Identified literature was screened by pairs of two individual reviewers (LM, EK, RH, and EM) by reading through titles and abstracts. Subsequently, full-text eligibility was determined by two independent reviewers. Disagreements were settled through discussion between the two reviewers. If an agreement could not be made, a third reviewer (PB or LM) made the final decision. Please see **Figure 1** for PRISMA flow chart.

[1]http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42017057988

Two reviewers screened titles and abstracts of 7,022 identified citations, excluding 6,296 publications that were outside the scope of the review. Main reasons for excluding studies at this stage were that studies either investigated only health outcomes, but not immersive nature-exposure, or immersive nature-exposure, but not health.

Subsequently, two reviewers assessed 726 publications in their full length. At this level, studies of types of nature-exposure that did not fall under the definition of immersive nature-experience were excluded. This, for example, included gardening activities (e.g., Sato and Conner, 2013) and school ground greening (e.g., Dyment and Bell, 2008), but also studies in which the place or uses of the natural environments could not be identified (e.g., Zhang et al., 2015). Additional reasons for excluding studies included specifications that, for example, activities occurred indoors (e.g., Siegel et al., 2015); that full-texts could not be obtained (e.g., Jelley, 2005); or the body of the text was written in languages not spoken by members of the review team (e.g., de Assis Pimentel, 2008).

The inclusion of publications identified through snowballing ($n = 135$) resulted in 461 publications included in the systematic review. Within these 461 publications, 489 individual studies were represented since some publications included more individual studies.

Data Items and Extraction Process

Data were obtained from the literature by a single investigator (LM and EK) using the same generic data extraction form. Data extracted from the literature included: study information (i.e., publication year, authors, and country in which the study was performed); study sample (i.e., sample size, sex, participant characteristics, e.g., information relating to any diagnoses, sociodemographic, or particular group affiliation, and age); study design [inspired by (Ryan et al., 2013)]; activity; duration of exposure; characteristics of natural and control conditions; outcome measures; and reported results. This information is displayed in **Tables 1–3**.

According to the context in which the nature-experience was inscribed, studies were divided into three sectors: (1) recreation; (2) social and health; and (3) day care and education. The first category included types of interventions and programs that occurred during healthy participants' free time, e.g., outside school or work hours. The second category encompassed types of interventions and programs that were used as a form of treatment or offer for specific ill, vulnerable or socially disadvantaged populations. The last category included studies that investigated interventions that were integrated in educational practice, e.g., education outside the classroom (EOtC), or add-ons to educational programs, e.g., semester-start courses or adventure education.

Risk of Bias in and Across Individual Studies

Given the wealth of identified literature and limited resources, we did not systematically assess risk of bias of the individual studies. Risk of bias for individual studies was narratively described. Special attention was given to selection bias related to appropriate randomization of group allocation. In the absence of randomization, we assessed whether recruitment strategies were likely to result in systematic differences between intervention and control groups, and whether sufficient information was provided to ascertain that groups were comparable. Other risk of bias focus areas included ascertainment bias, face-validity of constructs, carry-over effects, as well as attrition, verification, and reporting bias. Lastly, we considered whether power calculations were reported and if sample sizes seemed appropriate. The nature of the interventions makes it impossible to blind participants and instructors to group allocation which might introduce performance bias. However, if this was the only potential source of bias identified, we did not downgrade the quality of evidence at an outcome level. To provide a rough indication of level of evidence, studies were categorized according to the Cochrane Collaboration Study Design Guide (Ryan et al., 2013) from which typical potential sources of bias for the individual types of designs may deduced.

Additionally, we considered the strength of the quantitative, controlled evidence at an outcome level: if most of the studies were randomized, large-scale and without apparent issues relating to bias, we considered the quality of the evidence high. If randomization had been used in most of the studies, but the number of participants was limited, or other issues relating to bias were likely, we considered the quality moderate. If the evidence primarily was based on non-randomized studies, or there were apparent, serious issues relating to bias that could skew the results, we considered the quality of evidence low. If, for example, the effects of immersive nature-experience on psychophysiological stress response was based on a number of non-randomized studies and a few sufficiently powered, appropriately randomized cross-over trials, the quality of the evidence would be considered high. However, if the randomized studies were based on small samples, the quality would be rated moderate. If we additionally found that the studies did not cross-over and counter-balance the order of the exposures, and a carry-over effect would be likely to affect the investigated outcomes, further reductions in the overall assessment of the quality of evidence would be made.

Summary Measures and Synthesis of Results

Given the heterogeneity of outcomes and interventions, we did not consider meta-analyses appropriate. Results for individual outcomes were therefore not quantitatively synthesized but summarized by sector, health domain, and results and described narratively in the text (Green et al., 2006). Results were divided into four categories: (1) Intervention had significant positive effect on outcome; (2) intervention had significant positive or non-significant effect on subsets of outcome; (3) findings were non-significant; and (4) intervention had significant negative effect on outcome. Mixed findings thus indicated that subsets of the constructs or markers used to measure the same outcome displayed significantly positive changes, but other subsets were non-significant. For example, in a study investigating the effects of immersive nature-experience on mood, individual subscales that contribute to overall mood were considered subscales and not individual constructs. We did not come across any studies

TABLE 1 | Study characteristics, recreation.

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
RANDOMIZED CONTROLLED TRIAL								
Brown et al., 2014	UK	i: 27 c1: 27 c2: 19	$\bar{x}$ = 40.0 (SD: 10.6), office workers from international firm, ♀♂	Walking (measured during (1) relaxation (2) stressful task (3) after stressful task)	8 weeks (2*20 min weekly)	Mental and Physical	BMI Heart rate Heart rate variability Cardiovascular disease risk score Systolic and diastolic blood pressure Perceived general, physical, and mental health	No
QUASI-RANDOMIZED CONTROLLED TRIAL								
Calogiuri et al., 2015	Norway	i: 6 c: 5	$\bar{x}$ = 49 (SD: 8), healthy sedentary or moderately active individuals, ♀♂	Exercise (biking and rubber band exercises)	2 days (2*45 min a day)	Mental and physical	Affective state Blood pressure Serum cortisol Serum cortisol awakening response	Pa.[l]
Mao et al., 2012b	China	i: 10 c: 10	$\bar{x}$ = 20.79 (SD: 0.54), university students, ♂	Walking	2 days [2*1.5 h on the same day (morning and afternoon)]	Mental and Physical	BMI Cortisol Cytokine production Lymphocyte subsets Malondialdehyde level Mood SOD activity Testosterone	No
Bratman et al., 2015b	USA	i: 19 c: 19	$\bar{x}$ = 26.6, healthy adult urban residents, ♀♂	Walking	90 min	Mental and physical	Heart rate Respiration rate Rumination Subgenual prefrontal cortex (sgPFC)	No
Bratman et al., 2015a	USA	i: 30 c: 30	$\bar{x}$= 22.9, university students, ♀♂	Walking	50 min	Mental	Anxiety Cognitive performance Rumination Positive and negative affect	No
Ryan et al., 2010	Australia	80 (i and c N.R.)	18–22, university students, ♀♂	Walking	15 min	Mental	Vitality	No
Perkins et al., 2011	USA	i: 26 c1: 8 c2: 9	19–24, university students, ♀♂	Walking	20 min	Mental	Attention Concentration Mood Short term memory	No
Mayer et al., 2009	USA	76 (i and c N.R.)	N.R., university students, ♀♂	Walking	10 min	Mental	Cognitive performance Positive and negative affect Introverted and extroverted self-consciousness Reflection on negative memory	No
Mayer et al., 2009	USA	92 (i and c N.R.)	N.R., university students, ♀♂	Walking	10 min	Mental	Cognitive performance Positive and negative affect Introverted and extroverted self-consciousness Reflection on negative memory	No

(Continued)

TABLE 1 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
Mayer et al., 2009	USA	64 (i and c N.R.)	N.R., university students, ♀♂	Walking	10 min	Mental	Cognitive performance Positive and negative affect Introverted and extroverted self-consciousness Reflection on negative memory	No
Martens et al., 2011	Switzerland	i: 52 c: 44	$\bar{x}$ = 37.6, students, full time workers, retirees, ♀♂	Walking	30 min	Mental	Positive and negative affect Activation and arousal	No
CROSS-OVER TRIAL								
Beil and Hanes, 2013	USA	15	$\bar{x}$ = 42.3 (SD: N.R.), healthy "Non-Hispanic White" adults, ♀♂	Seated relaxation	20 min	Mental	Cortisol Salivary amylase Self-reported stress	No
Berman et al., 2008	USA	38	$\bar{x}$ = 22,62, university students, ♀♂	Walking	55 min	Mental	Cognitive performance	No
Gidlow et al., 2016	UK	38	$\bar{x}$ = 40,9 (SD: 17,6), university students, ♀♂	Walking	30 min	Mental	Cortisol Heart rate variability Mood Working memory	No
Hohashi and Kobayashi, 2013	Japan	27	12–14, ♀	(1) Seated relaxation and (2) walking	(1) 15 min (2) 30 min	Mental	Anxious mood Fatigue Refreshing mood Salivary amylase activity Tension and excitement	No
Johansson et al., 2011	Sweden	20	19–20, university students, ♀♂	Walking	40 min over 5 weeks (with or without friend)	Mental	Positive and negative affect Attention Perceived stress	No
Kerr et al., 2006	Japan	g1[l]: 22 g2: 22	g1: $\bar{x}$ = 22.7 (SD: 1.72) g2: $\bar{x}$ = 20.6 (SD: 1.29), university students, ♂	Running	N.R.	Mental	Somatic feelings Transactional emotions	No
Lee et al., 2009	Japan	12	20–23, university students, ♂	Seated relaxation	15 min	Mental and physical	Cortisol Systolic and diastolic blood pressure	No
Lee et al., 2011	Japan	12	N.R., university students, ♂	Seated relaxation	15 min	Mental and physical	Blood pressure Cortisol Heart rate variability Mood	No
Matsuura et al., 2011	Japan	26	19–25, university students, ♀♂	Horseback riding	30 min	Mental	Salivary alpha-amylase activity Heart rate variability Mood	No
Park et al., 2007	Japan	12	$\bar{x}$ = 22.8 (SD: 1.4), university students, ♂	(1) Walking and (2) seated relaxation	20 min	Mental	Cortisol Hemoglobin concentration in the prefrontal cortex	No
Park et al., 2008	Japan	12	$\bar{x}$ = 21.3 (±SD: 1.1), university students, ♂	Seated relaxation	15 min	Mental and Physical	Blood pressure Cortisol Heart rate variability Pulse	No

(Continued)

TABLE 1 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
Park, 2009	Japan	12	$\bar{x}$ = 21.8 (SD: 0.8), university students, ♂	(1) Seated relaxation and (2) walking	15 min	Mental and Physical	Blood pressure Cortisol Heart rate variability Pulse	No
Park et al., 2010	Japan	280	$\bar{x}$ = 21.7 (SD: 1.5), university students, ♂	(1) Seated relaxation and (2) walking	(1) 14 min (2) 16 min	Mental and physical	Blood pressure Cortisol Heart rate variability Mood Pulse	No
Park et al., 2011	Japan	168	$\bar{x}$ = 20.4 (SD: 4.1), university students, ♀♂	(1) Seated relaxation and (2) walking	15 min	Mental	Mood	No
Roe and Aspinall, 2011a	Scotland	24	g1: $\bar{x}$ = 46, individuals with mental diagnoses g2: $\bar{x}$ = 35, individuals without mental diagnoses, ♀♂	Guided walking	1 h	Mental	Mood Reflection over personal goals Self-esteem	No
Sahlin et al., 2016	Sweden	51	21–72, ♀♂	Guided relaxation	30 min	Mental and physical	Cognitive performance Blood pressure Cognitive fatigue Pulse	No
Schutte et al., 2017	USA	67	4–8, ♀♂	Walking	20 min	Mental	Cognitive performance Inhibitory control Working memory	No
Shin et al., 2011	South Korea	60	$\bar{x}$ = 23.27, university students, ♀♂	Walking	55 min	Mental	Cognitive performance Mood	No
Takayama et al., 2014	Japan	45	19–23, university students, ♂	(1) Seated relaxation and (2) walking	15 min	Mental	Emotional and cognitive restoration Mood Positive and negative affect Vitality	No
Tsunetsugu et al., 2007	Japan	12	$\bar{x}$ = 22.0 (SD: 1.0), university students, ♂	(1) Walking and (2) seated relaxation	15 min	Mental and physical	Cortisol Heart rate variability Systolic and diastolic blood pressure	No
Tyrväinen et al., 2014	Finland	77	$\bar{x}$ = 47.6 (SD: 8.68), ♀♂	(1) Seated relaxation and (2) walking	(1) 15 min (2) 30 min	Mental	Cortisol Creativity Positive and negative affect Vitality	No
Yamaguchi et al., 2006	Japan	10	$\bar{x}$ = 23.2 (SD: 1.1), healthy individuals, ♂	(1) Seated relaxation and (2) walking	20 min	Mental	Cortisol	No
CONTROLLED BEFORE-AND-AFTER STUDY								
Bertone, 2015	USA	i: 17 c1: 11 c2: 16	26–75, ♀♂	Yoga	1.5 h per week over 8 to 10 weeks	Mental and physical	Body awareness Cortisol Spiritual wellbeing Quality of life	No

(Continued)

TABLE 1 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
Furman and Sibthorp, 2014	USA	i: 57 c: 60	14–15, ♀♂	Outdoor adventure	14 days	Social	Expedition behavior Prosocial behavior	3 months
Gatersleben and Andrews, 2013	England	i: 17 c: 17	18–43, ♀♂	Walking [II]	10 min	Mental and physical	Affect Attention Heart rate	No
Li et al., 2008	Japan	i: 12 c: 11	35–56, individuals from four companies in Tokyo, ♂	Walking	3 days, 2 nights	Physical	Adrenaline Granulysin Granzymes Killer cells, amount and activity Lymphocytes Perforin T-cells	1 month (only i)
Orren and Werner, 2007	USA	i:67 c: 76	$\bar{x}$ = 14.64 (SD: 1.91), ♀♂	Wilderness program	1 day, 2 nights	Mental	Self-concept Internalizing and externalizing behaviors	No
Roe and Aspinall, 2011a	Scotland	i:83 c:40	i: $\bar{x}$ = 50 c: $\bar{x}$ = 44, individuals with or without mental diagnoses, ♀♂	Guided walking	1 h	Mental	Mood Reflection over personal goals Self-esteem	No
Thompson, 2014	UK	i: 33 c: 32	$\bar{x}$ = 44.5 (SD: 13.5), ♀♂	Walking	2*45 min per week over 8 weeks	Mental and physical	Arterial stiffness Blood pressure Cognitive function Eating habits Hemodynamic measures Physical activity Self-esteem	No
WITHIN-SUBJECTS WITHOUT CROSS-OVER								
Aspinall et al., 2015	Scotland	12	$\bar{x}$ = 30.08 (SD: N.R.), university students, ♀♂	Walking	~10 min	Mental	Activity in frontal cortex Frustration Engagement Arousal Meditation	No
Durr, 2009	USA	20	23–36, volunteers ♀♂	Adventure experience	N.R.	Mental	Subjective wellbeing	No
Fattorini et al., 2012	Italy	14	$\bar{x}$ = 23.9, college students, ♂	Walking	7–15 min	Physical	Oxygen consumption (VO2) Carbon dioxide output Pulmonary ventilation Respiratory exchange ratio Peak oxygen uptake and ventilatory threshold Heart rate	No
Li et al., 2011	Japan	16	36–77, healthy individuals, ♂	Walking	1 day, two sessions	Mental and physical	Adrenaline Noradrenalin Dopamine Blood pressure	No

(Continued)

TABLE 1 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
Li et al., 2016	Japan	19	40–69, ♂	Walking (2.6 km)	1 day, two sessions (80 min)	Mental and physical	Adrenaline Blood pressure Blood sugar Cholesterol Dopamine Mood Noradrenaline Pulse Serum insulin Serum triglyceride	No
Morita et al., 2007	Japan	498[III]	$\bar{x} =$ 56.2 (SD: 10.6), forest visitors, ♀♂	Forest visit ($\bar{x}$ = 5.7 km)	$\bar{x}$ = 2.2 h (SD: 51 min)	Mental	Anxiety Mood	No
Peacock et al., 2007	UK	20	31–70, members of organization that arranges activities in natural environments, ♀♂	Walking	N.R.	Mental	Self-esteem Mood	No
Reed et al., 2013	England	75	11–12, ♀♂	Running	10–20 min	Mental	Self-esteem Enjoyment of running	No
Toda et al., 2013	Japan	20	64–74, healthy individuals, ♂	Walking	45 min	Mental and physical	Blood pressure Cortisol Chromogranin A Pulse Self-reported stress Perceived fatigue and excitement	No

c, control group; c1, control group number 1; c2, control group number 2; i, intervention group; N.R., not reported; pa., partial; $\bar{x} =$ *sample mean (years, km or hours/min).*

[I]Two intervention groups. g1 consisted of occasional male runners, and g2 consisted of specialized male runners.

[II]The publication included two studies: one in which the impacts of qualities of natural environments, high vs. low refuge, were compared during a walk, and another in which a walk in the actual environment was compared to a sitting, indoor condition where the participants viewed the same walk on a screen.

[III]Participants were asked to join the project at entrance to a park. Comparison condition during holiday were participants were asked to fill out the same questionnaire. Therefore, it was not clear what comparison conditions entailed, although authors reported having controlled for physical activity. ♀, female participants; ♂, male participants.

TABLE 2 | Study characteristics, health and social.

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
RANDOMIZED CONTROLLED TRIAL								
Antonioli and Reveley, 2005	USA and Honduras	i:15 c:15	$\bar{x}$ = 40.2, individuals with diagnosis of mild or moderate depression without psychotic features, ♀♂	Animal-facilitated therapy	1 h per day over two weeks	Mental	Anxiety Depression	No
Lee and Lee, 2014	South Korea	i: 43 c:19	60–80, individuals of which a large proportion were taking various types of medications, ♀	Walking	1 h	Physical	Arterial stiffness Pulmonary function Systolic and diastolic blood pressure	No
Sonntag-Öström et al., 2015	Sweden	i:51 c:48	24–60, individuals diagnosed with exhaustion disorder, ♀♂	Relaxation exercises, seated relaxation in solitude, walking	2*4 h per week over 11 weeks	Mental	Anxiety Attention capacity Depression Fatigue Level of burnout Mood Perceived generalized stress Self-concept Self-esteem Sick leave	12 months
QUASI-RANDOMIZED CONTROLLED TRIAL								
Chun et al., 2017	South Korea	i:30 c:29	36–79, individuals with stroke, ♀♂	Forest bathing (meditation and walks)	4 days, 3 nights	Mental	Anxiety Biological antioxidant potentials Depression Reactive oxygen metabolite levels	No
Gelkopf et al., 2013	Israel	i:22 c:20	24–59, patients with chronic war-related PTSD, ♂	Adventure rehabilitation program, sailing and expeditions	3 h per week + 2*3 days over 1 year	Mental and social	Depression PTSD symptoms Social function Quality of life Control of symptoms Hope	No
Hepperger et al., 2016	Austria	i:25 c:23	55–75, patients who had undergone knee surgery, ♀♂	Guided hiking program	2–3 h per week, 3 months	Physical	Functional test (walking on stairs) Muscle strength Self-reported general functionality/wellbeing	2 months
Jelalian et al., 2006	USA	i:37 c:39	13–16, overweight, ♀♂	Adventure therapy + cognitive behavioral therapy	1 session per week, 16 weeks	Mental, social and physical	BMI Peer rejection Self-perception Social support	6 months
Jelalian et al., 2010	USA	i: 62 c: 56	13–16, overweight, ♀♂	Adventure therapy	1 session per week, 16 weeks	Physical	BMI Waist circumference Physical activity	12 months

(Continued)

TABLE 2 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
Jelalian et al., 2011	USA	89 (i and c N.R.)	13–16, overweight, ♀♂	Adventure therapy	1 session per week, 16 weeks	Mental, social and physical	BMI Peer rejection Social anxiety Self-perception	8 months
Johansson et al., 2015	Sweden	i:31 c:7	20–65, individuals with long-lasting mental fatigue after either a traumatic brain injury or stroke, ♀♂	Walking	1 session per week, 8 weeks	Mental	Anxiety Attention capacity Depression Perceived mental fatigue Self-pity	No
Mao et al., 2012a	China	i:12 c:12	60–75, individuals with hypertension, ♀♂	Forest bathing, (walking and relaxation)	2*1.5 h daily over 1 week	Mental and physical	Blood pressure Cytokines (IL-6, TNF) Endothelin Homocysteine Subcomponents of renin-angiotensin system Mood	No
Paquette and Vitaro, 2014	Canada	i1: 101 i2: 109	$\bar{x}$ = 20, juvenile delinquents, ♀♂	Wilderness therapy	i1: 8–10 days i2: 17–20 days	Mental and social	Accomplishment motivation Antisocial behaviors Interpersonal skills Socio-professional status	3 and 6 months
Scheinfeld et al., 2016	USA	i:159 c:18	22–66, veterans, ♂	Outward bound (OB4V)	6 days	Mental and social	Masculine role conformity Mental health (symptoms, interpersonal relations, and social role performance)	No
Shin et al., 2012	South Korea	i:47 c:45	$\bar{x}$ = 45.26, alcoholics upon inpatient treatment, ♀♂	Forest therapy (games, climbing, walking, orienteering, meditation, coaching)	9 days	Mental	Depression	No
CLUSTER-RANDOMIZED CONTROLLED TRIAL								
Zachor et al., 2017	Israel	i: 30 c: 21	3.4–7.4, diagnosed with autism, ♀♂	Outdoor adventure	30 min weekly, over 13 weeks	Social	Social functioning	No
CROSS-OVER TRIAL								
Berman et al., 2012	USA	20	$\bar{x}$ = 26.0, patients diagnosed with major depressive disorder, ♀♂	Walking	50–55 min	Mental	Short term memory Positive and negative affect Negative memories and feelings toward self	No
Taylor and Kuo, 2009	USA	17	7–12, diagnosed with ADHD, ♀♂	Walking	20 min	Mental	Cognitive performance	No
Frühauf et al., 2016	Austria	14	$\bar{x}$ = 32.7 (SD: 10.8), patients diagnosed with mild to moderate depression, ♀♂	Walking	60 min	Mental	Affective valence Mood	No

(Continued)

TABLE 2 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
hspace*-0.01ptKjellgren and Buhrkall, 2010	Sweden	18	$\bar{x} = 36.83$, individuals with stress or exhaustion disorders, ♀♂	Seated relaxation	30 min	Mental and physical	Systolic and diastolic blood pressure Perceived stress Pulse	No
Mann, 2007	USA	35	13–17, at-risk, ♀	Outdoor adventure program*	Unclear. Min. 4 days	Mental and social	Identity Mattering Perceived social support Self-confidence Self-esteem	2 weeks
Neunhäuserer et al., 2013	Austria	17	$\bar{x} = 43.9$ (SD: 8.3), suicidal patients, ♀♂	Hiking	2–3 sessions of 2–2.5 h over 9 weeks	Mental	Cytokines (IL-6, TNF, S100)	No
Roe and Aspinall, 2011a	Scotland	24	g1: $\bar{x} = 46$, individuals with mental diagnoses g2: $\bar{x} = 35$, individuals without mental diagnoses, ♀♂	Guided walking	1 h	Mental	Mood Reflection over personal goals Self-esteem	No
Song et al., 2015	Japan	20	$\bar{x} = 58$, individuals with hypertension, ♂	Walking	17 min	Mental	Heart rate variability Mood	No
Sonntag-Öström et al., 2014	Sweden	20	$\bar{x} = 41.6$, patients with stress-related burnout syndrome, ♀	Seated relaxation	3*90 min	Mental	Attention capacity Mood Systolic and diastolic blood pressure	No
Sturm et al., 2012	Austria	i1: 10 i2: 10	i1: $\bar{x} = 45.1$ (SD: 10.4), i2: $\bar{x} = 41.0$ (SD: 6.3), suicidal patients, ♀♂	Hiking	3*2–3 h per week, 9 weeks	Mental	Depression Hopelessness Thoughts of suicide Sense of belonging	No
CONTROLLED BEFORE-AND-AFTER STUDY								
Ang et al., 2014	Singapore	i:76 c:60	13–18, truant behavior, ♀♂	Outward Bound, co-curricular activity	5 days	Mental	Goal setting Problem solving School attendance	1 and 3 months
Barton et al., 2012	England	i: 24 c1: 14 c2: 14	21–83, individuals with various mental diagnoses, ♀♂	Walking	45 min per week, 6 weeks	Mental	Mood Self-esteem	No
Eikenaes et al., 2006	Norway	i:16 c:37	i: $\bar{x} = 36$ (SD: 9.1) c: $\bar{x} = 37$ (SD: 11.4), patients with avoidant personality disorder, ♀♂	Wilderness therapy	6 days + 3 days (total of 11.5 weeks at hospital)	Mental and social	Avoidance Depression Interpersonal problems Self-efficacy Generalized symptoms of psychopathology	12 months
Gill et al., 2016	USA	i:50 c:66	18–39, cancer survivors, ♀♂	Outdoor adventure therapy	7 days	Physical	Self-reported physical activity Perceived barriers for physical activity	3 months

(Continued)

TABLE 2 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
Guthrie, 2004	USA	i: 39 c: 33	6–17, mental or emotional disorders, ♀♂	Forest therapy (using Cognitive Behavior Therapy)	2 h weekly, 9 weeks	Mental	Problem Severity Functioning	No
Han et al., 2016	South Korea	i:33 c:28	25–49, individuals with widespread chronic pain, ♀♂	Forest therapy (based on Cognitive Behavior Therapy, for individuals with chronic pain, also includes mindfulness, physical activity, music therapy etc.)	2 days	Mental and physical	Depression Heart rate variability Natural killer cells Perceived pain Quality of life	No
Hough and Paisley, 2008	USA	14[I]	N.R., adults with disabilities, ♀♂	Adventure program	3 days	Mental	Empowerment Situational control	No
Kim et al., 2009	Korea	i: 23 c1: 19 c2: 21	i: $\bar{x} = 38.6$ (SD: 11) c: $\bar{x} = 43.6$ (SD: 13.6) c1: $\bar{x} = 43.3$ (SD: 8.35), patients with major depressive disorder, ♀♂	Forest therapy (using Cognitive Behavior Therapy-Based Psychotherapy)	4 weeks [4 sessions (3 h each)]	Mental	Heart rate variability Cortisol Depression General health	No
Larson, 2007	USA	i:31 c: 30	9–17, behavioral issues, ♀♂	Adventure camp	5 days	Mental	Self-concept	No
Margalit and Ben-Ari, 2014	Israel	i:64 c: 29	14–16 at-risk, ♂	Wilderness therapy	Unclear [II]	Mental	Self-efficacy Cognitive autonomy	5 months
Romi and Kohan, 2004	Israel	i: 36 c1: 88 c2: 33	15–18, drop-outs, ♀♂	Wilderness adventure therapy	6 days	Mental	Self-esteem Locus of control	No
Rosenberg et al., 2014	USA	i: 162 k: 234	18-39, cancer-patients, ♀♂	Outward bound program	6 days	Mental	Body image Self-compassion Self-esteem Depression Alienation	No
Schell et al., 2012	Australia	i: 21 c: 12	12–25, individuals with mental diagnoses, ♀♂	Outdoor adventure group	7 weeks (1 day per week over 6 weeks, then 3 days excursion)	Mental and Social	Self-esteem Self-control Social connectedness	No
Sung et al., 2012	South Korea	i:28 c:28	i: $\bar{x} = 63$ (SD: 11) c: $\bar{x} = 66$ (SD: 7), individuals with hypertension, ♀♂	Forest therapy (using Cognitive Behavior Therapy)	8 weeks	Mental and physical	Blood pressure Cortisol Quality of life	1, 4, and 8 weeks

(Continued)

TABLE 2 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow-up
Thomas, 2004	Australia	i:14 c:8	i: $\bar{x}$ = 31.54 (SD: 10.37) c: $\bar{x}$ = 38.38 (SD: 12.14), individuals with acquired brain injury, participants or previous participants in rehabilitation program, ♀♂	Outward bound + outdoor experiential education	9 days + pre and post meetings and activities (total approx. 5–6 months)	Mental	Quality of life	6 months and 2 years
Voruganti et al., 2006	Canada	i:23 c:31	i: $\bar{x}$ = 32.04 (SD: 7.51) c: $\bar{x}$ = 40.83 (SD: 9.44), clinically stabilized schizophrenia patients, ♀♂	Group based adventure therapy	8 months	Mental and social	Cognitive dysfunction Functionality Self-esteem Social, professional, and mental functioning Schizophrenia symptom severity Weight	12 months
Walsh, 2009	USA	i:43 c:43	13–17, referrals from justice system, at-risk and criminals, ♀♂	Wilderness adventure program	21 days (8 days expedition and 4 days solo)	Mental and social	Hope Recidivism Resilience Risk of recidivism Self-efficacy	6 months
Wells, 2004	USA	i: 86 c: 35	12–26, individuals with risky behaviors (and their families), ♀♂	Challenge-based recreation	4 days	Social	Family function Conflict solving	6 weeks
WITHIN-SUBJECTS WITHOUT CROSS-OVER								
van den Berg and van den Berg, 2011	Netherlands	12	9–17, diagnosed with ADHD, ♀♂	Stay at care farms	1 h	Mental	Cognitive performance Mood	No

c, control group, c1, control group number 1; c2, control group number 2; i, intervention group; N.R., not reported, $\bar{x}$ = sample mean (years, km or hours/min).
[I]Nested control group: i and c both undergo treatment and two different adventure programs.
[II]consisted of participants who participated in a full program (10 weekly preparation meeting involving camping and outdoor skills as well as a 4-day expedition) and partial program. Not clear what a partial program entailed.
♀, female participants; ♂, male participants.

TABLE 3 | Study characteristics, education.

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow -up
QUASI-RANDOMIZED CONTROLLED TRIAL								
Connelly, 2012	USA	i: 18 c: 18	13–16, ♀♂	Adventure-based counseling	1 day	Mental and social	Self-efficacy Self-concept	No
Lethbridge et al., 2005	Canada	i:16 c: 17	$\bar{x} = 19$, nursing students, ♀♂	Walking (following lecture)	1 h	1 time	Directed attention Attention fatigue Mood Quality of life	No
Mutz and Müller, 2016	Germany	i: 15 c: 7	19–25, university students, ♀♂	Hiking, co-curricular	8 days	Mental	Perceived stress Self-efficacy Attention to surroundings Perceived wellbeing	No
O'Brien and Lomas, 2017	England	i:103 c: 93	N.R., children from three schools, ♀♂	Outdoor personal development course	5 days	Mental	Self-efficacy Resilience Growth mindset	1 month
White, 2012	England	i: 24 c: 24	$\bar{x} = 13$ (SD: 7), social and emotional challenges, ♀♂	Outdoor Education	3 months	Mental	Self-concept	No
CROSS-OVER TRIAL								
Roe and Aspinall, 2011b	Scotland	18	$\bar{x} = 11$, ♀♂	Forest school	5 h	Mental	Mood Reflection on personal development	No
Wood et al., 2014	England	60	♀: $\bar{x} = 13$ (SD: 0.5) ♂: $\bar{x} = 12.9$ (SD: 0.6)	Orienteering	20 min	Mental and physical	Self-esteem Physical activity	No
CONTROLLED BEFORE-AND-AFTER STUDY								
American Institutes for Research, 2005	USA	i: 125 c: 109	N.R. (6.th grade students), at-risk, ♀♂	Outdoor science school	5 days	Mental and social	Cooperation Conflict solving skills Self-esteem Problem solving Motivation for learning Academic performance Relationship to peers School behavior	6–10 weeks
Ang et al., 2014	Singapore	i:76 c:60	13–18, truant behavior, ♀♂	Outward bound, co-curricular activity	5 days	Mental	Goal setting Problem solving School attendance	1 and 3 months
Beightol, 2012	USA	i:51 c:54	N.R., fifth grade students, ♀♂	Experiential, adventure-based program (Anti-Bullying Initiative)	10 sessions of 2 h in school setting, 3 excursion days	Mental	Empathy Goal setting Problem solving Resilience Self-efficacy	4 months
Bailey and Kang, 2015	USA	i:95 c:200	N.R., first-year, bachelor art students, ♀♂	Wilderness orientation	10 days (measured over 1 semester)	Mental and Social	Life purpose Self-efficacy Social support	3–4 months

(Continued)

TABLE 3 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow -up
Collins, 2014	USA	i:91 c:65	16–24, university students, ♀♂	Extended wilderness education experience	1 semester	Mental	Problem solving	No
Dettweiler et al., 2017	Germany	i:37 c: 11	$\bar{x}$ = 11.23 (SD: 0.46), ♀♂	Education outside the classroom	1 day weekly over one school term	Mental and physical	Cortisol Physical activity	No
Duerden et al., 2009	USA	i:45 c: 43	11–15, ♀♂	Adventure recreation	2 weeks	Mental	Identity formation antecedents	No
Ewert and Yoshino, 2011	USA	i:28 c:27	N.R., university students, ♀♂	Adventure education	3 weeks (measured over 1 semester)	Mental	Resilience	2 years (interviews)
Fjørtoft, 2004	Norway	i:46 c:29	5–7, ♀♂	Free play	9 months	Physical	Motor skills	No
Foley, 2009	USA	i:193 c:93	+14 years, volunteers, ♀♂	Outward Bound	5–22 days	Mental and social	Leadership skills Personal development Social and environmental awareness	6 months
Frauman and Waryold, 2009	USA	i1: 18 i2: 65 c: 25 [I]	N.R., participants in residential learning community and students, ♀♂	Wilderness-based program	4 days (measured over 1 semester)	Mental and Social	Life effectiveness	No
Fuller et al., 2017	England	i:12 c: 12	14–16, underachieving academically, ♀♂	Outdoor residential experiences	Two 3–day sessions yearly, over 3 years	Mental	Academic performance Self-efficacy	No
Gatzemann et al., 2008	Germany	i:26 c:19	19–27 ($\bar{x}$ = 22.79, SD: 1.99), university students (sports), ♀♂	Outdoor education	2*8 days	Mental	Self-value Social self-esteem Bodily self-esteem	No
Gehris, 2007	USA	i: 27 c1: 13 c2: 14	N.R., 10th grade technical students, ♀♂	Adventure education	24 sessions of 40 min over 44 days	Mental and physical	Self-esteem Physical self-concept Physical fitness	No
Johnson-Pynn et al., 2014	Uganda	i:12 c:71	16-24, students from secondary school and members of Wildlife Clubs of Uganda, ♀♂	Environmental education workshops	2–3 days	Mental and social	Self-efficacy Social competencies Leadership skills	No
Harris, 2005	USA	i:29 c:54	16–21, high school students with special needs, ♂	Adventure education	5 days	Mental and social	Academic achievement Self-efficacy School attendance	10 days
Hayhurst et al., 2015	New Zealand	i: 63 c: 63	i: $\bar{x}$ = 16.55, high school students c: $\bar{x}$ = 19.42, university students, ♀♂	Developmental voyage	10 days	Mental	Resilience	No
Hayhurst et al., 2015	New Zealand	i: 72 c: 74	i: $\bar{x}$ = 16.51 c: $\bar{x}$ = 16.43, ♀♂	Developmental voyage	10 days	Mental	Resilience Self-esteem Self-efficacy Social effectiveness	5 months

(Continued)

TABLE 3 | Continued

Reference	Country	Sample size	Target group	Program content	Duration	Health domain(s)	Outcome(s)	Follow -up
Hunter et al., 2013	New Zealand	i:31 c: 31	$\bar{x}$ = 16.48, ♀♂	Developmental voyage	10 days	Mental	Self-esteem	No
Hunter et al., 2013	New Zealand	i:132 c: 264	i: $\bar{x}$ = 16.28 c: $\bar{x}$ = 17.25, ♀♂	Developmental voyage	10 days	Mental	Self-esteem	12 months
Hunter et al., 2010	New Zealand	i:33 c: 33	i: $\bar{x}$ = 15.79, high school students c: $\bar{x}$ = 19.69, university students, ♀♂	Developmental voyage	10 days	Mental	Self-efficacy	No
Hunter et al., 2010	New Zealand	i:82 c: 31	i: $\bar{x}$ = 15.79 c: $\bar{x}$ = 15, ♀♂	Developmental voyage	10 days	Mental	Self-efficacy	5 months
Kafka et al., 2012	New Zealand	i:27 c: 33	i: $\bar{x}$ = 16.21 c: $\bar{x}$ = 16.25, ♀♂*	Developmental voyage	10 days	Mental and social	Self-esteem Gender prejudice	No
Kafka et al., 2012	New Zealand	i:89 c: 53	i: 14–18 c: 15–18, ♀♂	Developmental voyage	10 days	Mental and social	Self-esteem	4–5 months
Darrin Kass, 2011	USA	i:12 c:21	$\bar{x}$ = 26.58, university students, ♀♂	Outdoor Management Training	3–4 days (full course 14 weeks)	Social	Leadership skills	No
McKenzie, 2015	USA	i: 19 c: 14 [II]	N.R., primary school students, grades 0 to 5, ♀♂	Access to outdoor classroom	6 months	Social	Social environment in classroom	No
Paquette et al., 2014	USA	i: 32 c1: 17 c2: 35	i: $\bar{x}$ = 17.9 c1: $\bar{x}$ = 18.3 c2: $\bar{x}$ = 16.4, college students, ♀♂	Developmental adventure program	18 days	Mental	Self-esteem	2 months
Sanders et al., 2005	Canada	i:14 c: 18	23–51, registered nurses enrolled in associate degree, ♀♂	Walking	60 min (after lecture)	Mental	Cognitive performance Perceived attention	No
Shirilla, 2009	USA	N.R.	11–12, students enrolled in program, ♀♂	Adventure-based Program	2 school years	Social	Social skills	No
Sibthorp et al., 2015, p. 2015	N.R.	i:32 c:45	$\bar{x}$ = 19.8, volunteers to NOLS course work, ♀♂	Adventure education	3 semesters (70–90 days)	Mental	Self-regulation	4 weeks
Vlamis et al., 2011	USA	i:32 c:45	N.R., first-year college students, ♀♂	Adventure orientation program	6 days	Mental and social	Autonomy Goal setting Interpersonal relations	5 months

c, control group; c1, control group number 1; c2, control group number 2; I, intervention group, N.R., not reported; $\bar{x}$, sample mean (years, km or hours/min).

[I]*In all groups, there was a large percentage of participant who dropped out of the study from allocation, baseline measures and post measures. i1 consisted of 38 participants, but at the first measurement the number of participants was reduced to 18. Likewise, i2 encompassed 81 participants before the first measurement where only 65 showed up. At the post-measurement, only 35 were included. In c, only 25 participated in pre and post measurements.*

[II]*Participants were primary school teachers, but the subject of the research was the classroom environment, e.g., relationships between students. ♀, female participants; ♂, male participants.*

in which some subsets were negatively affected and some non-significant or positive and do therefore not include this category. In the text, we present findings according to the categories relating to type of intervention under the three sectors, i.e., recreation, health and social, and education.

RESULTS

Study Characteristics

The included studies mainly derived from USA ($n = 174$), UK ($n = 63$), Denmark ($n = 32$), Japan ($n = 28$), Australia ($n = 24$), Norway ($n = 19$), Canada ($n = 18$), New Zealand ($n = 15$), Sweden ($n = 14$), South Korea ($n = 10$), Austria ($n = 7$), Germany ($n = 5$), and Switzerland ($n = 5$). Other countries represented were Finland, Israel, Italy, Iran, Malaysia, Croatia, Bulgaria, Peru, Tanzania, Uganda, and Brazil.

Amongst the 489 included studies, ≈5% were existing reviews ($n = 23$), ≈23% qualitative analyses ($n = 115$), ≈13% a combination of quantitative and qualitative analyses ($n = 62$), and ≈59% quantitative analyses ($n = 289$). Amongst the 315 studies including quantitative analyses, ≈42% involved control groups or conditions ($n = 133$), e.g., randomized controlled-trials, randomized cross-over trials, and controlled before-and-after studies, and ≈69% of the quantitative studies ($n = 218$) did not involve a control group or condition, e.g., before-and-after and case studies. See **Tables 1–3** for characteristics of the individual quantitative, controlled studies and **Supplementary Material C** for a full list of references for qualitative and observational, quantitative studies.

Participants included healthy adults, adolescents and children as well as populations with behavioral or emotional disturbances [e.g., Attention Deficit/Hyperactivity Disorder (ADHD) or depression], substance abuse issues, delinquent behaviors, social disadvantage, or who were overweight. Amongst all the identified research, ≈28% included only child and adolescent populations ($n = 129$) under the age of 18.

Results were grouped under psychological wellbeing ($n = 97$; ≈55% positive; ≈13% mixed; ≈29% non-significant; 2% negative); psychosocial function ($n = 67$; ≈61% positive; ≈9% mixed; ≈30% non-significant); psychophysiological stress response ($n = 50$; ≈58% positive; ≈18% mixed; ≈24% non-significant); cognitive performance ($n = 36$; ≈58% positive; ≈6% mixed; ≈33% non-significant; 3% negative); social skills and relationships ($n = 34$; ≈70% positive; ≈7% mixed; ≈22% non-significant); and physical health, e.g., risk of cardiovascular disease ($n = 51$; ≈37% positive; ≈28% mixed; ≈35% non-significant). See **Table 4** for results from all outcomes groups, divided by sector, and **Supplementary Material D** for all individual outcomes. **Table 4**, for example, shows that we found 57 studies in which positive results were reported, 22 that reported mixed results, 31 non-significant results, and one negative results on mental health outcomes within the recreation sector.

In the following, findings are presented in relation to types of interventions and programs categorized by sector, i.e., recreation, health and social, or education, and domain, i.e., mental, physical, and social health. Any identified meta-analyses and reviews are presented first, followed by supplementary, individual studies.

Recreational Immersive Nature-Experience

Recreational immersive nature-experience encompassed free-time activities and programs in which healthy participants partook voluntarily. The most common type of activities included short-termed walks or seated relaxation. These activities were sometimes practiced more times over several days in conjunction with cognitive or behavioral therapy. This was often termed *shinrin-yuko* or forest bathing. We found 168 studies that explored relationships between recreational immersive nature-experience and health of which ≈82% ($n = 138$) included mental, ≈52% physical ($n = 88$), and ≈17% social health ($n = 29$) outcomes. Seven reviews addressed various forms of nature-experience in the recreational sector and presented the literature in a manner allowing for extraction of results from studies relating to immersive nature-experience (Thompson, 2006; Bischoff et al., 2007; Tsunetsugu et al., 2010; Bratman et al., 2012; Voutselas, 2012; Konijnendijk et al., 2013; Haluza et al., 2014).

Below, we focus on reviews and studies that were based quantitative, controlled analyses given the wealth of material. Please see **Table 1** for a full summary of quantitative, controlled analyses from the recreational sector.

Mental Health

Psychological wellbeing

Several distinct psychological wellbeing constructs were investigated in the identified literature: positive and negative affect; perceived stress; vitality; quality of life; mental and spiritual wellbeing; anxiety; rumination; internalizing and externalizing behaviors, and mood states. Overall, the number of interventions that had a positive ($n = 22$) or mixed effect on these outcomes ($n = 13$) outweighed the number of non-significant findings ($n = 11$) (see **Table 4** for the distribution of positive, negative, mixed, and non-significant findings for the individual outcomes). Mixed findings indicate that subsets of the constructs used to measure the outcome displayed significantly positive changes, but not all. Mixed findings were frequent for the outcome mood states. This is discussed further in the following. Given the predominant use of non-randomized designs with small sample sizes and the dispersion of the findings between and, for the outcome mood states, within the distinct outcome constructs, strong conclusions could not be accumulated, and the quality of the evidence was considered low. Below, we provide examples of the interventions and findings.

Levels of self-reported positive affect were increased relatively more for participants when they walked in natural environments compared to urban environments (Mayer et al., 2009; Johansson et al., 2011; Martens et al., 2011; Takayama et al., 2014; Tyrväinen et al., 2014; Bratman et al., 2015a; Calogiuri et al., 2015), but the same could generally not be observed for negative affect (Mayer et al., 2009; Johansson et al., 2011; Martens et al., 2011; Takayama et al., 2014; Bratman et al., 2015a). Roe and Aspinall (2011a) observed that participants with and without mental diagnoses reported decreased stress and enhanced happiness. This was

TABLE 4 | Outcomes across sectors and health domains.

	Recreation				Health & Social				Education				Total					
	+	+/	/	–	+	+/	/	–	+	+/	/	–	+	+/	/	–	% *p*	% *p*+m
Mental health	57	22	31	1	50	5	28	1	37	5	12	1	144	32	71	3	57.6	70.4
Psychological wellbeing	22	13	11	0	26	2	16	1	5	0	0	1	53	15	27	2	54.6	70.1
Psychophysiological stress-indicators	23	9	12	0	5	0	0	0	1	0	0	0	29	9	12	0	58.0	76.0
Cognitive indicators	9	0	5	1	5	1	1	0	7	1	6	0	21	2	12	1	58.3	63.9
Psychosocial indicators	3	0	3	0	14	2	11	0	24	4	6	0	41	6	20	0	61.2	70.1
Physical health	6	10	7	0	12	4	10	0	1	0	1	0	19	14	18	0	37.3	64.7
Cardiovascular indicators	5	7	5	0	3	3	1	0	0	0	0	0	8	10	6	0	33.3	75.0
Immune function	1	3	1	0	2	1	1	0	0	0	0	0	3	4	2	0	33.3	77.8
Body composition and function	0	0	1	0	4	0	6	0	1	0	1	0	5	0	8	0	38.5	38.5
Active behaviors	0	0	0	0	3	0	2	0	0	0	0	0	3	0	2	0	60.0	60.0
Social health	1	0	0	0	15	0	6	0	12	3	4	0	28	3	10	0	68.3	75.6
Supportive environments	0	0	0	0	4	0	2	0	0	1	0	0	4	1	2	0	57.1	71.4
Behaviors	1	0	0	0	3	0	1	0	1	0	1	0	5	0	2	0	71.4	71.4
Skills and relationships	0	0	0	0	8	0	3	0	11	2	3	0	19	2	6	0	70.4	77.8
Total *n*	64	32	38	1	77	9	44	1	50	8	17	1	191	49	99	3	55.8	70.2

+: Intervention had significant positive effect on outcome (raw count), –: Intervention had significant negative effect on outcome (raw count), +/: Intervention had significant positive or nonsignificant effect on subsets of outcome (raw count), /: Findings were non-significant (raw count), % p: Percentage of total that had positive effect on outcome, %p + m: Percentage of total that had positive or mixed effect on outcome.

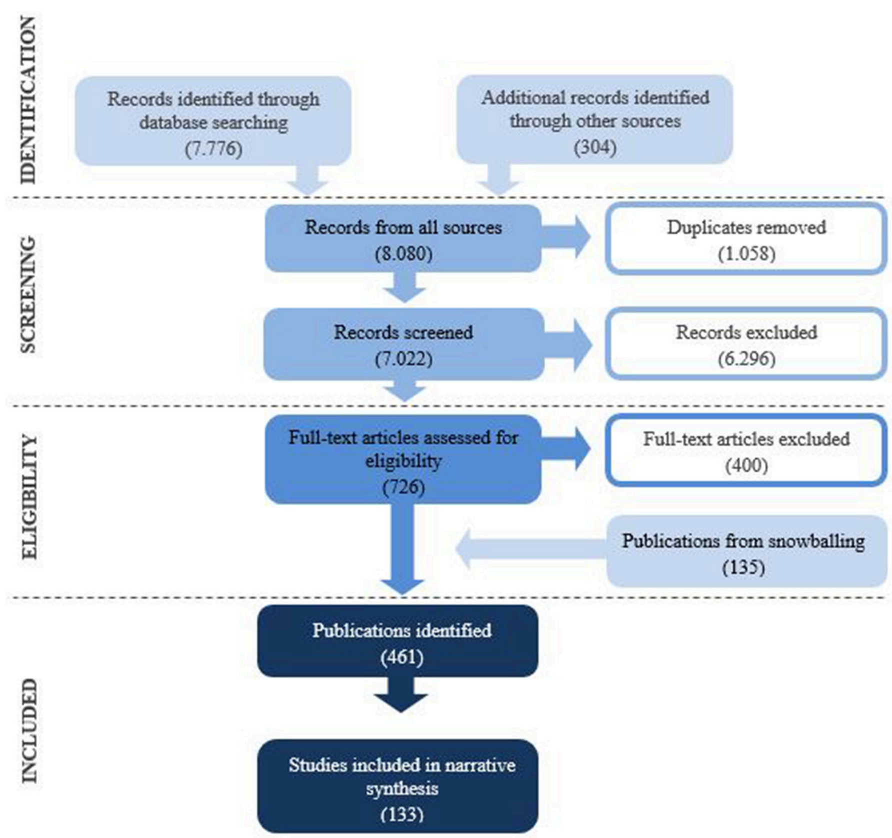

FIGURE 1 | Flow chart.

supported in two other studies evaluating the effects of short-termed walks for healthy adults (Beil and Hanes, 2013; Toda et al., 2013). In another study, no significant stress reducing effects was reported (Johansson et al., 2011). Quality of life and spiritual wellbeing was not found to differ following weekly yoga practice over a period of 8 to 10 weeks in natural environments compared to indoors (Bertone, 2015).

Mixed findings stemmed from studies of the effects of short-termed immersive nature-experience on self-reports of transient mood states, encompassing anxiety, anger, vigor, fatigue, depression, and confusion subscales. Here, we treat these subscales as distinct parts of mood, not as individual constructs. Twelve studies investigated effects of short-termed, i.e., 15 min to 2 days (Peacock et al., 2007; Park et al., 2010, 2011; Lee et al., 2011; Matsuura et al., 2011; Perkins et al., 2011; Shin et al., 2011; Mao et al., 2012b; Hohashi and Kobayashi, 2013; Takayama et al., 2014; Li et al., 2016), and 8 weeks of repeated short-termed recreational immersive nature-experience (Thompson, 2014). In all studies, it was reported that some constructs relating to these mood states were improved, although some subscales remained unchanged. No individual constructs consistently changed across the studies. For example, across short exposures in 14 different types of forests, Park et al. (2011) found that all subscales, except for the construct depression, were improved in comparison to exposures to various urban environments. Comparatively, Peacock et al. (2007) found that anger, confusion, depression, and anxiety were relatively more improved, while no such difference could be observed for vigor and fatigue. Likewise, upon an 8 week program, reductions in anxiety and depression were observed, but not the other mood states (Thompson, 2014). The findings relating to individual, distinct mood states seem to point in various directions. As such, immersive nature-experience may improve mood, but the finer distinctions remain unclear.

Psychophysiological stress-indicators

We found that positive findings ($n = 23$) only just outweighed mixed ($n = 9$) and insignificant ($n = 12$) findings across all psychophysiological indicators of stress, i.e., heart rate variability; cortisol; adrenaline; noradrenaline; dopamine; salivary amylase; and cortisol awakening response[2]. More uncommon approaches to measuring acute stress response included activity in the frontal cortex and hemoglobin concentration in the prefrontal area of the brain. The studies were mainly designed as randomized, cross-over trials with small samples. Most of the studies ($n = 13$) included university students of which most were male (85% of the studies). Based on the types of designs and sample sizes used, we considered the overall quality of the evidence moderate. The investigated types of interventions are elaborated in the following and may be supplemented by results from the health and social sectors which are reviewed in section Psychophysiological stress-indicators.

Short-termed walking or seated relaxation in natural environments was frequently ($n = 9$) found to reduce psychophysiological stress indicators (Lee et al., 2009, 2011, 2014; Park et al., 2010; Li et al., 2011, 2016; Mao et al., 2012b; Toda et al., 2013; Aspinall et al., 2015) more than the same activities in control conditions. Amongst these studies, Toda et al. (2013) compared a physically active natural environment condition with a sedentary indoor condition. As such, results may have been affected by differences relating to differences of PA and not the conditions as such. Six studies also investigating the effects of short-termed walking or seated relaxation reported mixed (Park et al., 2007, 2008; Tsunetsugu et al., 2007; Park, 2009; Calogiuri et al., 2015; Lee et al., 2015) and eight insignificant findings (Yamaguchi et al., 2006; Matsuura et al., 2011; Beil and Hanes, 2013; Hohashi and Kobayashi, 2013; Brown et al., 2014; Tyrväinen et al., 2014; Bertone, 2015; Gidlow et al., 2016), but none directly negative outcomes of the programs.

Calogiuri et al. (2015) found that some, but not all, stress-indicators were improved more upon work day breaks involving green exercise (i.e., biking and rubber band exercises) compared to when the same exercises were performed indoors. Brown et al. (2014) did not find an influence of walking in natural environments during breaks in the work day. Likewise, Matsuura et al. (2011) did not find differences in stress-indicators upon a short horseback ride in natural environments compared to an indoor simulator.

Cognitive indicators

A number of distinct cognitive indicators were investigated within the recreation sector: cognitive task performance; creativity; attention; concentration; inhibitory control; working memory; and short-term memory. Positive findings marginally outweighed ($n = 9$), negative ($n = 1$), and non-significant findings ($n = 5$). The included studies were designed as randomized cross-over trials with small samples, and the overall quality of evidence was considered moderate.

Short-termed walking in natural environments was frequently found to enhance cognitive performance more than the same activities in control conditions (Berman et al., 2008; Mayer et al., 2009; Shin et al., 2011; Sahlin et al., 2016). Indicators of creativity (Tyrväinen et al., 2014) and working memory (Gidlow et al., 2016) were likewise enhanced more after walking in natural environments compared to urban control conditions. One study reported that no differences relating to attention, concentration, and working memory could be observed when comparing three contexts, i.e., one natural and two built environments (Perkins et al., 2011), and another that participants performed worse in an attention task after a walk in a park (Johansson et al., 2011). We found one study conducted with children in which it was found that preschool children responded more quickly in an attention task following a walk in natural environments compared to urban environments (Schutte et al., 2017), but no differences could be observed relating to regulative control and verbal working memory.

Physical Health

Cardiovascular indicators

Findings within the recreation sector related to cardiovascular indicators, i.e., acute changes in blood pressure and cardiovascular disease risk factors, were more often absent

[2]Heart rate is sometimes used as an indicator of stress-related phenomena. However, heart rate is subject to a multitude of physiologic cardiac functions and therefore not an interpretationally robust measure of stress.

($n = 5$) or mixed ($n = 7$) than positive ($n = 5$). The included studies were mainly designed as randomized, cross-over trials with small samples. Based on the types of designs and sample sizes used, we considered the overall quality of the evidence moderate.

Acute reductions in blood pressure were most often mixed ($n = 6$) or insignificant ($n = 2$): only three studies reported larger reductions in blood pressure after exposure to natural than comparison environments. Haluza et al. (2014) reviewed partially overlapping studies using blood pressure measures, amongst other physiological indicators, and echoed the finding. In addition to studies reviewed by Haluza et al. (2014) and Mao et al. (2012b) found that ET-1, a so-called vasoconstrictor involved with the progression of cardiovascular disease, was reduced subject to two walks in natural environments, but not urban environments amongst a small sample of healthy adults. Likewise, Thompson found that arterial stiffness and hemodynamic measures, both associated with cardiovascular risk of disease, were improved differentially following an 8 week walking program (Thompson, 2014). Another indicator of the occurrence and development of cardiovascular disease, platelet activation, was not significantly different (Mao et al., 2012b), nor was the Framingham cardiovascular disease risk score (Brown et al., 2014).

Immune function

Four controlled studies investigated the effects of short-termed immersive nature-experience on outcomes related to immune function, i.e., so-called oxidative stress (i.e., the disturbance in the balance between the production of free radicals and antioxidant defenses), pro-inflammatory cytokines (i.e., signaling molecules that mediate innate immune response), and leukocyte or white blood cell subsets. The evidence for impacts of immersive nature-experience on the immune system in healthy subjects was spread over many indicators related to oxidative stress, pro-inflammatory cytokines, and leukocyte subsets. Findings were positive ($n = 1$) or mixed ($n = 4$). The included studies were based on between- and within-subjects designs and included small samples, and the overall quality of evidence was considered low to moderate.

Programs of 3 days including one or two walks in forested areas a day were found to have positive effects on a number of immune function indicators, but some subsets were unchanged. study (Li et al., 2008): Leukocyte subsets, i.e., the number of CD3+ cells; granulsyn; granzymes A/B expressing cells; natural killer cells; and perforin, were increased post nature-programs, but not after the same walking activities in urban environments. However, differences in overall white blood cell counts were non-significant. Another study identified no significant effects on immunoglobin A (Tsunetsugu et al., 2007). A quasi-randomized trial (Mao et al., 2012b) included reports of a vast number of immune function indicators: levels of serum pro-inflammatory cytokines were reduced in the forest group; indicators of oxidative stress status were mixed, i.e., levels of malondialdehyde was decreased, but T-SOD not significantly different; and the distribution of leukocyte subsets was likewise mixed, i.e., the levels of B-lymphocytes were increased, but the percentage of natural killer cells; T; T-helper; and T-suppressor lymphocytes were not significantly different.

Social Health

In the absence of controlled studies relating to social health in the recreation sector, we here discuss findings from observational studies. Konijnendijk et al. (2013) reviewed research on the benefits of recreational use of urban parks, including aspects such as social interaction, collective efficacy, and sense of community. The review included mainly correlational studies of which only three studies explicitly addressed immersive nature-experience as defined in the present review. The scarcity of relevant literature identified in this review corresponds with our review. These studies, two qualitative and one observational, quantitative, indicated that adults and children alike considered that urban green space was a place that enhanced social support and social interaction. The authors of the review found that the field of research was limited and deemed the certainty of the evidence weak, as studies were mainly qualitative or observational (Konijnendijk et al., 2013). Due to the use of designs with no control group, the quality of the evidence for the outcomes related to supportive environments, i.e., social interaction and support, was low.

Immersive Nature-Experience in Social and Health Sectors

One hundred-and-seventeen studies investigated health outcomes of immersive nature-experience in the social and health sectors of which ≈86% included mental ($n = 147$), ≈52% physical ($n = 89$), and ≈36% social health ($n = 62$) outcomes. Thirteen reviews addressed various forms of nature-experience in social and health sectors and presented the literature in a manner allowing for extraction of results from studies relating to immersive nature-experience (Bedard, 2004; Wendell, 2004; Bischoff et al., 2007; Grinde and Patil, 2009; Shanahan et al., 2009; Annerstedt and Währborg, 2011; Lubans et al., 2012; Bowen and Neill, 2013; Ejbye-Ernst, 2013; Norton, 2014; Poulsen et al., 2015; Bettmann et al., 2016; Fernee et al., 2017). Programs were similar in content to those of recreational immersive nature-experience but were targeted and adapted to a range of unhealthy, disadvantaged, or at-risk populations. Intense and demanding expeditions in wild or urban nature or short-and-longer termed primitive camp-based experiences were a predominant type of activity within the sector. Please see **Table 2** for a full summary of quantitative, controlled analyses from the social and health sectors.

Mental Health

Psychological wellbeing

A vast range of outcomes related to psychological wellbeing were investigated in the health and social sector. Some measures represented clinical assessments, i.e., symptoms of psychopathology; schizophrenia; depression; anxiety; and post-traumatic stress disorder (PTSD). Others related to more generalized or non-clinical assessments of positive and negative affect; stress; mood states; depressive states; fatigue; level of burnout; anxiety; thoughts of suicide; negative memories and feelings toward self; quality of life; general wellbeing; and internalizing and externalizing behaviors. Most findings were positive ($n = 26$). One study indicated that fatigue was improved more during the comparison condition, which included a mindfulness course (Johansson et al., 2015). Two studies in the sector reported mixed and 16 non-significant findings. The quality of the evidence was considered low to moderate and is discussed further in the following.

Sustained expedition or base camp adventure experiences in natural environments were commonly used in a variety of social and health care contexts and applied amongst diverse target groups. In a comprehensive meta-analysis based primarily on observational studies, Bowen and Neill (2013) reported that outdoor behavioral health care was associated with moderate effect sizes for psychological state and level of mental functioning, an aggregate measure of parameters such as anxiety and locus of control ($g = 0.5$). However, associations were absent at follow-up. Participants were most commonly male, between age 10 and 17, resided in USA, identified as at-risk and Caucasian (Bowen and Neill, 2013). Populations were characterized as abuse victims; adjudicated youth; behaviorally disordered; disabled; educationally disengaged; emotionally disturbed; having mental health issues; having physical issues (exemplified by brain injury or weight-loss); and substance abusers. The authors observed a substantial level of heterogeneity in the outcome estimates across the individual original studies and found that study, program and, participant characteristics partially explained the variance. Age was highlighted as a singular predictor that influenced the achieved associations: older participants, who more often volunteered to participate than younger participants, achieved larger improvements. Therefore, despite the vastness of the research, the generalizability of the results is questionable. Since subsequent controlled studies have supported the positive findings (e.g., Gelkopf et al., 2013; Scheinfeld et al., 2016), we considered the quality of the evidence for positive associations and effects on psychological wellbeing of adventure experiences in nature low to moderate amongst adolescent and adult populations.

Short-termed seated relaxation and walking in natural environments was found to improve various indicators of self-reported wellbeing. Patients diagnosed with mild to moderate depression reported improved mood indicators and affective valences upon a 60 min walk compared to indoor biking and resting (Frühauf et al., 2016). However, affective valences did not differ significantly from the indoor active control group. Patients with major depressive disorder reported higher levels of positive affect, but similar levels of negative affect, after a 50–55 min of walking in natural environments compared to urban environments (Berman et al., 2012). Likewise, women diagnosed with exhaustion disorder reported improved mood indicators upon three 1.5 h long sessions of seated relaxation in a forest compared to an urban environment (Sonntag-Öström et al., 2015). Mood indicators were likewise higher after 90 min of seated relaxation in three different natural environments compared to a parking lot in an urban area amongst patients with stress-related burnout syndrome (Sonntag-Öström et al., 2014). Amongst two different groups of individuals with and without mental diagnoses, 1 h of guided walking in a natural environment compared to urban environments resulted in higher ratings of mood, with the largest effect sizes observed amongst individuals with mental diagnoses (Roe and Aspinall, 2011a). Similar effects were found for mood indicators amongst hypertensive males after 17 min of walking in a natural environment (Song et al., 2015), compared to urban environments. Thirty minutes of seated relaxation in a forest was found to reduce perceived stress amongst individuals with stress or exhaustion disorders, although no more than the indoor control condition which involved watching a slideshow of the same forest environment (Kjellgren and Buhrkall, 2010). The quality of the evidence was considered moderate being based both randomized and non-randomized controlled designs and small study samples.

Interventions of longer duration with repeated exposures were also investigated. Participants with various mental diagnoses displayed improved mood indicators following a 6-week walking program in natural urban and rural environments, but changes were no larger than two control groups who underwent alternative treatments (social activities and swimming) (Barton et al., 2012). For individuals diagnosed with hypertension, two daily sessions with seated relaxation and walking in forests over a week improved mood indicators more than the same activities in an urban environment did (Mao et al., 2012a).

Patients characterized as high-risk suicidal reported lower levels of depression and hopelessness after a 9 week program with triweekly hikes compared to a waitlist control group (Sturm et al., 2012). Individuals with mental fatigue following acquired brain injury did not report improved anxiety or depression after 8 weeks of weekly 1.5 h walks in a park compared to participants taking part in face-to-face or online mindfulness courses (Johansson et al., 2015).

Two days of forest therapy in conjunction with cognitive behavior therapy provided small effects on self-reported depression and perceived pain amongst individuals with widespread chronic pain (Han et al., 2016). A similar 4-week forest therapy program provided larger reductions in depressive symptoms than a no treatment control and alternative treatment hospital-based control group for patients with major depressive disorder (Kim et al., 2009). Depression and anxiety decreased amongst patients with chronic stroke who partook in a 4 day forest bathing intervention, while no such changes could be observed in the control group who performed similar activities in an urban environment (Chun et al., 2017). Likewise, alcoholics' depression ratings decreased after a 9 day forest therapy camp with no changes occurring in the control group (Shin et al., 2012). The reviewed wellbeing indicators were multifarious, and the included studies covered a range of populations. As such, across various wellbeing measures, immersive nature-experience seemed to be beneficial, but the finer distinctions remained uncertain. The quality of the evidence was considered low to moderate.

Psychosocial indicators

There was a vast amount of research indicating that outdoor behavioral health care improved psychosocial parameters (Cason and Gillis, 1994; Hattie et al., 1997; Wilson and Lipsey, 2000;

Bedard, 2004; Bowen and Neill, 2013; Bettmann et al., 2016)[3]. The identified psychosocial outcomes represented interrelated yet different phenomena, such as identity formation; confidence; autonomy; locus of control; empowerment; resilience; daily functioning; and self-compassion, -efficacy, -esteem, -concept, -perception, -pity, and -control. Overall, outcomes were often improved ($n = 14$), but many were non-significant ($n = 11$) or mixed ($n = 2$). Due to the predominant use of pre-post designs with no randomization and the dispersion of outcomes, the quality of evidence for these outcomes was considered low.

Bowen and Neill (2013) reported that outdoor behavioral health care was associated with moderate increase in self-concept, which was an aggregate measure of, amongst other parameters, self-efficacy and self-control ($g = 0.3$). Bedard (2004) compared changes in self-esteem and self-concept in delinquent youth, who participated in outdoor behavioral health care with delinquent youth who engaged in standard processes of probation or rehabilitation. Outdoor behavioral health care was considerably more favorable.

Psychophysiological stress-indicators

As was observed amongst healthy populations (see section Psychophysiological stress-indicators), short-termed walking or seated relaxation in natural environments was found to reduce psychophysiological stress-indicators, i.e., heart rate variability and cortisol. Amongst the included studies, measures were exclusively found to be improved ($n = 5$). The studies in the social and health sector investigating psychophysiological stress-indicators were mainly designed as controlled before-and-after studies with small samples. Only one study was a cross-over trial. We considered the quality of evidence low to moderate. However, if findings from healthy populations may be translated to the populations included in this section, the evidence could be considered moderate. Examples of interventions and outcomes are provided in the following.

In a randomized cross-over trial, walking for 17 min increased heart rate variability more than the same activities in control conditions for middle-aged males with pre-hypertensive or stage 1 hypertension (Song et al., 2015). Longer-term forest therapy likewise enhanced psychophysiological stress indicators amongst individuals with hypertension (Sung et al., 2012), major depressive disorder (Kim et al., 2009), and chronic pain (Han et al., 2016).

Academic achievement and cognitive indicators

Identified outcomes representing cognitive indicators included cognitive performance; attention capacity; short term memory; and goal setting. These were predominantly improved ($n = 5$), but some were mixed ($n = 1$) or non-significant ($n = 1$). Interventions included short-termed walks and seated relaxation, and sustained expeditions and adventure programs. Quality of evidence is discussed in relation to these types of interventions below.

In the meta-analysis described in section Psychological wellbeing, Bowen and Neill (2013) reported that participation in sustained expeditions and adventure programs was associated with moderate improvements in school achievement, e.g., academic performance in English, Math, and Reading ($g = 0.41$). Associations were absent at follow-up. The research was based on studies about outdoor behavioral health care and behaviorally unadjusted adolescents in schools. Therefore, these findings are also relevant to the education sector (section Psychological and psychophysiological wellbeing indicators). The cognitive parameters were scattered and based on mainly observational studies. Given that the studies were based on a wealth of types of designs, many of which utilized poor or no control groups, the quality of the evidence was deemed low.

As was observed amongst healthy populations (see section Cognitive indicators), walking or sitting in nature provided larger acute enhancements in cognitive indicators than the same activity in control conditions: patients diagnosed with major depressive disorder displayed an enhanced short term memory upon walking in a park relatively to an urban environment (Berman et al., 2012). Likewise, women diagnosed with exhaustion disorder (Sonntag-Öström et al., 2015) had improved attention capacity upon three 1.5 h long sessions of seated relaxation in a forest compared to an urban environment. Patients diagnosed with mild to moderate depression participated in an 11 week program consisting of relaxation exercises, seated relaxation in solitude, and walking in a forest environment (Frühauf et al., 2016). Here, it was found that attention capacity was increased after single forest visits, but there was no effect found for the rehabilitation period as a whole when comparing measures to a waitlist control group (Frühauf et al., 2016). Amongst children diagnosed with ADHD (Taylor and Kuo, 2009), acute increases in cognitive performance after a 20 min walk in a natural environment compared to an urban environment. These studies were designed as randomized cross-over trials and one as a randomized controlled trial (RCT), thereby providing a moderate quality of evidence.

Physical Health

Body composition and physical health

Physical health in the social and health sector was investigated using diverse indicators of bodily function, i.e., pulmonary function; progress in walking rehabilitation; muscle strength; sick leave; perceived pain; and body composition measures, i.e., body-mass index (BMI) and waist circumference. Cardiovascular indicators, i.e., blood pressure and biomarkers of cardiovascular disease risk, and immune function indicators, i.e., oxidative stress, pro-inflammatory cytokines, and leukocyte subsets, were also used. Lastly, various indicators relating to PA were applied ($n = 5$). Most of the studies found that individual outcomes were improved ($n = 14$), but quite a few reported mixed ($n = 4$) and non-significant ($n = 10$) findings. Given that the evidence

[3]The majority of the original studies included in the meta-analyses by Bedard (2004) and Bettmann et al. (2016) were also included in the meta-analysis by Bowen and Neill (2013). Since the reviews by Bedard (2004) and Bettmann et al. (2016) focused on different target groups, the overlap between these two reviews was insubstantial: only one original study was included in both. The references (Cason and Gillis, 1994; Hattie et al., 1997; Wilson and Lipsey, 2000) pertain to reviews published previously to the period covered in this review, but were obtained when snowballing references and provide a supplement to the more recent reviews and meta-analysis.

was predominantly based on observational or controlled pre-post studies without allocation randomization, the quality of the evidence was deemed low.

In the abovementioned meta-analysis, Bowen and Neill (2013) concluded that outdoor behavioral health care was associated with a small effect size related to the participants' bodily function and physical health, exemplified by changes in weight and so-called somatic health ($g = 0.32$). However, associations had decreased at follow-up ($g = 0.23$). A substantial level of heterogeneity in the outcome estimates across the original studies was observed. Hence, the understanding of the mechanisms that cause the observed changes were limited and generalization should be practiced with caution. While the meta-analysis (Bowen and Neill, 2013) primarily was based on observational studies, subsequent experimental, controlled studies have supported the conclusions: outdoor behavioral health care interventions contributed to an enhancement of PA and reductions of the participants' BMI (although no larger than an alternative PA intervention), but improvements were absent at follow-up (Jelalian et al., 2010, 2011). Caution should be taken in interpreting these results since changes in weight and BMI provide inaccurate measures of unhealthy body fat and general bodily health.

Social Health

Social skills, relationships, and behaviors

Most studies in the social and health sector indicated positive social health outcomes ($n = 15$), although some reported non-significant findings ($n = 6$). The outcomes were spread over a number of measures, for example relating to the participants' social environment, i.e., family function; social support; alienation; and sense of belonging. Social behavior outcomes included antisocial behaviors; social avoidance; and ability to maintain socio-professional status. Lastly, social skills and relationships included outcomes social cognition and functioning; amount of conflict; and interpersonal relationships and problems. Given that the studies utilized a vast number of outcomes and were based on non-randomized designs, the evidence was deemed low to moderate.

In addition to, and partly overlapping with, the results from the above mentioned original studies, Bowen and Neill (2013) concluded that outdoor behavioral health care interventions associated with the participants' social development ($g = 0.42$), e.g., alienation and social skills, and family development ($g = 0.36$), e.g., parent-child relationship and family functioning. Associations were absent by follow-up. Across five original studies, Bedard (2004) found that interpersonal competencies and behavioral change in delinquent youth was positively influenced by participation in outdoor behavioral health care, and that this form of treatment was preferable to standard processes of probation or rehabilitation. Most of the studies on which the reviews were based used non-controlled designs and the quality of evidence was considered low to moderate.

The effects of nature-based sustained expedition or base camp adventure experiences on risky health behaviors were also investigated. Bowen and Neill (2013) collapsed substance use with other parameters, such as recidivism and home behavior, into one behavior-oriented outcome category, and found that the observed associations ($g = 0.41$) remained at follow-up, although reduced ($g = 0.21$). Due to the predominant use of non-controlled designs, the evidence was considered low quality.

Immersive Nature-Experience in Education

The final sector, immersive nature-experience used in educational context, encompassed 172 individual studies ≈72% included mental ($n = 124$), ≈16% physical ($n = 27$), and ≈58% social health ($n = 100$) outcomes. Three reviews addressed various forms of nature-experience in the education sector and presented the literature in a manner allowing for extraction of results from the studies relating to immersive nature-experience (Furie, 2011; Daniel et al., 2014; Cooley et al., 2015). Adventure education was the main type of activity. Other types of activities included green breaks from teaching and various types of educational activities taking place in natural environments. Please see **Table 3** for a full summary of quantitative, controlled analyses from the education and daycare sectors.

Mental Health

Psychosocial indicators

The dominant type of mental health category in the education sector was psychosocial indicators. Positive findings ($n = 24$) outweighed mixed ($n = 4$) and non-significant ($n = 6$) findings. Frequent outcomes were self-efficacy; self-esteem; and resilience. Other outcomes that were used on a more sporadic basis included self-concept; life effectiveness; sense of identity; autonomy; self-regulation; and the development of a so-called Growth Mindset which is a form of openminded or adaptive thinking. Given that the research was based mainly on small samples and controlled designs with no group allocation randomization, the evidence for the outcomes was considered low quality.

The main type of intervention was sustained adventure-based experiences in natural environments. Adventure education programs ranging from four to ∼90 days of varying intensity were found to increase psychosocial indicators such as self-esteem (Romi and Kohan, 2004; Mann, 2007; Kafka et al., 2012; Hunter et al., 2013; Hayhurst et al., 2015), self-efficacy (Hunter et al., 2010; Connelly, 2012; Fuller et al., 2017), self-concept (White, 2012), and resilience (Hayhurst et al., 2015) more than comparison conditions. A few studies in the education sector reported mixed effects on the psychosocial outcomes. For example, Gehris (2007) found that 44 days of adventure education improved the 10th grade pupils' self-esteem more than the control group that had undergone a health education programme, but not more than the control group that participated in a PA program. No effect on self-concept could be observed following the same program in comparison to either control group (Gehris, 2007).

Academic achievement and cognitive indicators

Effects of extra- and co-curricular and curriculum-integrated immersive nature-experience on problem solving; goal setting; attention capacity; and academic performance were investigated. Overall, positive effects of the interventions ($n = 7$) were almost matched by the number of non-significant findings ($n = 6$), with one study displaying mixed effects. Since the studies used small samples and did not randomize allocation to groups, the evidence was considered low quality.

Extra- and co-curricular immersive nature-experience for adolescents and young adults provided some positive and non-significant findings. For examples, adventure education as a co-curricular activity for adolescents with truant behavior was found to improve goal setting but not problem solving (Ang et al., 2014) and weekly sessions of outdoor residential experiences improved academically underachieving adolescents' academic performance (Fuller et al., 2017).

Whereas extra- and co-curricular adventure education was usually oriented toward shorter or longer durations of time removed from everyday life, included studies also addressed the potentials of outdoor activities in nature that were inscribed in educational practices. Studies, for example, investigated whether a break from lectures in the form of a 1 h walk in natural environments would increase the capacity to direct attention of undergraduate nursing students (Lethbridge et al., 2005) and diploma-prepared nursing students enrolled in a baccalaureate nursing program (Sanders et al., 2005). Results were inconclusive: in both studies, comparison groups, who did not participate in any form of restorative experience, also increased directed attention scores. In consequence, it seems the results indicated a learning effect rather than an effect of walking in a natural environment. This, however, did not imply inefficacy of natural environments to induce attention restoration, but rather a method weakness related to repeated use of measurement instruments that were not developed for such use. Amongst children, it was found that a 5-day science teaching program in a forest lead to improvements in motivation and attention capacity, as well as academic performance, amongst elementary school children in comparison to similar children who went to school as usual (American Institutes for Research, 2005). Research on EOtC in natural environments, a more long-termed, curriculum-integrated approach than the 5 day science teaching program, resulted in similar findings indicated by an observational study (Mygind, 2005).

Psychological and psychophysiological wellbeing indicators

The number of outcomes categorized under psychological wellbeing (positive effects: $n = 5$, negative effect: $n = 1$) and psychophysiological stress-indicators (positive effect: $n = 1$) was limited and we therefore present them together. Included outcomes were mood states; quality of life; mental wellbeing; purpose in life; self-reported stress; and the psychophysiological indicator of stress response, cortisol. Being based on mainly non-randomized study designs and small sample sizes, the evidence was considered low quality.

Interventions ranged from breaks from studying in natural environments (Lethbridge et al., 2005) and curriculum-integrated forest school (Roe and Aspinall, 2011b) to co-curricular hiking trips (Mutz and Müller, 2016). For example, nursing students reported increased mood states and quality of life (Lethbridge et al., 2005). Likewise, children who participated in 5 h of forest school reported improved mood (Roe and Aspinall, 2011b). Cortisol levels, indicative of stress response, were decreased when elementary school students partook in EOtC over 1 year in comparison to typical classroom-based education (Dettweiler et al., 2017).

Interestingly, a 10-day wilderness orientation experience was associated with a decrease in first-year university students' sense of purpose in life (Bailey and Kang, 2015). The authors argued that occurrences unrelated to the program caused the decline in sense of life purpose (Bailey and Kang, 2015). This is probable since outcomes were measured before and after the first semester at university (and not the program), a time of substantial stimuli and rapid development. Furthermore, the study was based on a nonequivalent controlled pre-post design in which participants self-selected into intervention and control groups. As such, the design would be susceptible to influence from these exogenous factors.

Physical Health

Motor skills and physical activity

We found a limited number of studies about physical health promotion outcomes within the education sector. We identified only two which were based on controlled designs. In these motor skills and physical fitness was assessed. We therefore discuss the observational literature within the sector related to physical health. Considering the scarcity of controlled studies and the use of small samples, the quality of the evidence for these outcomes was considered low.

There were indications that outdoor activities in nature that were integrated in pedagogical practice can enhance preschool-aged children's PA and motor skills. Motor skills are believed to be an important predictor of later life PA (Larsen et al., 2015; Lima et al., 2017a,b). In a preschool context, children's motor skills improved more when participating in daycare taking place in a forest environment compared to children who went to a traditional kindergarten (Fjørtoft, 2004). The observation was supported by an observational study (Vigsø and Nielsen, 2006).

Indicators of PA were mainly used as an acute and highly context-dependent indicator of bodily movement during immersive nature experience. As such, perhaps unsurprisingly, no studies compared PA before and after interventions. Research on EOtC in natural environments, a form of recurring nature-integrated teaching that stems from Scandinavia (Bentsen et al., 2009b; Jordet, 2010), was consistently found to encourage higher levels of moderate to vigorous PA (MVPA) than traditional, classroom-based teaching (Grønningsæter et al., 2007; Mygind, 2007, 2016; Dettweiler et al., 2017). For example, children were estimated to spend 11.5 min longer in MVPA per 2 h unit, averaged over three seasons (Dettweiler et al., 2017).

Social Health

Social skills and relationships

Social health promotion outcomes within the education sector were most often oriented toward social skills and relationships, i.e., cooperation skills; social competence; amount of conflict and conflict resolution skills; peer relations; interpersonal relations; and knowledge about bullying. Other outcomes included perceived social support; bullying; and school attendance.

Mostly, interventions had significant positive effects on outcomes ($n = 12$). Some cases were mixed ($n = 3$) or non-significant ($n = 4$). The quality of the evidence was considered low and is discussed further in relation to the main types of interventions in the following.

A review and three subsequently published original studies reported that various aspects of cooperation skills, such as trust in the group, responsibility, leadership and mutual aid, were improved after both short and long term outdoor education interventions (Frauman and Waryold, 2009; Ewert and Overholt, 2010; Harun and Salamuddin, 2010; White, 2012; Cooley et al., 2015). The review (Cooley et al., 2015) included four controlled studies, two of which were published within the time frame reviewed in the present systematic review (Harun and Salamuddin, 2010; Vlamis et al., 2011), as well as qualitative and observational studies which are not discussed here. The studies included children, adolescents, and adults. While the studies reported promising developments in cooperation skills pre to post programs, the transferability of the skills to everyday life remained uncertain. These types of outdoor education interventions were also found to associate with reduced gender-based prejudice (Kafka et al., 2012) and an increase in knowledge about bullying amongst adolescents, although no direct effect on bullying was observed (Furie, 2011). Effects of adventure-based pre-orientation courses for first-year university students on social competencies (Frauman and Waryold, 2009), social support (Bailey and Kang, 2015), and interpersonal relations (Vlamis et al., 2011) were mixed. The quality of the evidence for effects relating to cooperation skills, gender-based prejudice, bullying, knowledge about bullying, social competences, social support, and interpersonal relations was considered low.

Research on immersive nature-experience integrated into pedagogical and didactical practice provided mixed results. Elementary school students, who took part in a 5-day outdoor science school intervention, rated their conflict resolution and cooperative skills higher than waitlist controls (American Institutes for Research, 2005). Likewise, teachers estimated that the intervention group improved their conflict resolution skills, peer relations, and behavior in class more than the waitlist controls. Over the course of a 6-month outdoor class intervention, McKenzie (2015) could not observe any differences in teacher-reported changes in the quality of peer relations (i.e., friction and cohesion between students) between the intervention and control group. Furthermore, McKenzie (2015) did not report differences between competition orientation and the amount of problems in the class. The intervention and control groups were not completely comparable: students were recruited from different schools and differed in terms of ratio of ethnic minorities and socio-economy with more poor and ethnic minority backgrounds in the intervention group. In supplementary observational studies, it was indicated that participation in EOtC was associated with making more friends and higher levels of social wellbeing (Mygind, 2005, 2009). The used study designs in conjunction with small sample sizes provided the background for considering the quality of the evidence low.

DISCUSSION

The aims of this systematic review were to investigate (1) what types of immersive nature-experience, (2) which health promotion outcomes had been investigated, and (3) how immersive nature-experience influenced or associated with mental, physical, and social health outcomes. Here, we briefly summarize the key findings relating to (1) prominent types of immersive nature-experience and (2) the most commonly investigated outcomes and associated findings. To provide an overview across the three sectors used above, we also (3) discuss the two main types of immersive nature-experience, short-termed walks, and seated relaxation and adventure-based activities, and associated findings. Since these activities were more often found in the recreational or social and health sectors, we also briefly discuss findings from the educational sector. Lastly, we elaborate on the development of the body of research before discussing strengths and limitations of the present work.

Prominent Types of Immersive Nature-Experience

Within the recreational sector, the most common type of activity included short-termed walks or seated relaxation, frequently termed *shinrin-yuko* or forest bathing. In the social and health sector, interventions were similar in content to those of recreational immersive nature-experience, but targeted and adapted to a range of unhealthy, disadvantaged, or at-risk populations. The main type of intervention was sustained expeditions and adventure programs in which participants were challenged mentally and physically through activities in natural environments. In the educational sector, adventure education was predominant, but other types of activities included green breaks from teaching and various types of educational activities taking place in natural environments, e.g., forest school or EOtC.

Prominent Health Promotion Outcomes

Use of immersive nature-experience was most frequently positively, or positively and non-significantly, associated with mental, social, and physical health outcomes. We found conditional support for positive effects on a range of health promotion outcomes grouped under psychological wellbeing ($n = 97$; ≈55% positive; ≈13% mixed; ≈29% non-significant; 2% negative); psychosocial function ($n = 67$; ≈61% positive; ≈9% mixed; ≈30% non-significant); psychophysiological stress response ($n = 50$; ≈58% positive; ≈18% mixed; ≈24% non-significant), and cognitive performance ($n = 36$; ≈58% positive; ≈6% mixed; ≈33% non-significant; 3% negative); and social skills and relationships ($n = 34$; ≈70% positive; ≈7% mixed; ≈22% non-significant). Findings related to outcomes categorized under physical health, e.g., risk of cardiovascular disease, were less consistent ($n = 51$; ≈37% positive; ≈28% mixed; ≈35% non-significant). Only three studies indicated a negative impact of immersive nature-experience on cognitive performance (Johansson et al., 2011), life purpose (Bailey and Kang, 2015), and fatigue (Johansson et al., 2015). Across the sectors, mental health outcomes were the dominant type of outcome. Since these were often psychosocial in character, e.g., self-esteem or self-concept, many mental health outcomes could also be categorized as social health outcomes.

Health Promotion Outcomes of Short-Termed Immersion in Nature

Across the recreational and social and health sectors, walking, and seated relaxation in natural environments was most frequently found to enhance aspects of wellbeing; reduce stress; and enhance cognitive performance. However, wellbeing measures were diverse and aspects of wellbeing, e.g., individual scales relating to depressive or anxious moods, were not consistently improved. Likewise, the connection between exposure to natural environments while walking or during seated relaxation and acute reductions in psychophysiological indicators of stress was somewhat obscured by a relatively high proportion of mixed or insignificant findings. Much of the research focused on adults, especially university students.

It may seem surprising that the amount of research identified within the field of attention restoration was not larger. In a recent meta-analysis, Ohly et al. (2016) concluded that across 31 studies, some cognitive measures (i.e., Digit Span Forward, Digit Span Backward, and Trial Making Test B) were improved upon exposure to visual representations of natural environments, exposures to natural environments, and views to natural environments. As such, many of these studies were not eligible for inclusion in the present review of immersive nature-experience. However, the findings may supplement the studies identified in the present review.

Health Promotion Outcomes of Adventure-Based Activities in Nature

Intense and demanding expeditions in wild or urban nature or primitive camp-based experiences targeted toward behavioral change, or personal or social development, appeared to have immediate effects on psychosocial indicators; the ability to engage in social contexts; cooperation skills; family development; behavior (e.g., substance abuse and crime); and physical health (e.g., changes in body weight) across a range of populations. There were indications that behavioral changes endured at follow-up. The activities were mainly inscribed in the educational or social and health sectors. The activities, pedagogies, and places of the programs under investigation were generally poorly described which hinders transfer and reproducibility of the study results. The evidence for the effects of outdoor behavioral health care and outdoor education amongst children is limited, perhaps because the practice is more common amongst adolescents and young adults. For example, the abovementioned meta-analysis (Bowen and Neill, 2013) included only four studies addressing (unspecified) impacts of outdoor education and outdoor behavioral health care amongst children under the age of 9 years.

Health Promotion Outcomes of Educational Activities in Nature

Use of immersive nature-experience in educational contexts, e.g., schools or kindergartens, was positively associated with mental, social, and physical health outcomes. The research was mainly based on correlational studies that were spread over a range of outcomes and contexts, and we therefore considered the quality of the evidence low. Recent large-scale EOtC studies have supplied that 3 h of weekly EOtC increased boys' MVPA (Schneller et al., 2017a) and girls light PA (Schneller et al., 2017b) considerably over a full 7-day week when compared to students in a traditional classroom setting. Furthermore, the children who participated in EOtC over the course of 1 year maintained a higher level of motivation for school (Bølling et al., 2018). The studies were based on types of EOtC that did not exclusively occur in natural environments, but also other informal learning settings. Subsequent analyses will investigate whether the environments had differential impacts (Nielsen, 2016).

Developments in the Research Field

In agreement with previous reviews about immersive nature-experience, or *friluftsliv*, we found that the body of research was characterized by a considerable volume and interdisciplinary breadth (Sandell, 2004; Schantz and Silvander, 2004). The main focus of previous reviews was on Scandinavian literature, but attempts were made in previous reviews to also include research published in English language (Sandell, 2004; Schantz and Silvander, 2004). While contributions from outside of Scandinavia predominantly derived from USA at the time of the previous reviews, we unearthed a considerable body of literature from Asian countries relating to the phenomenon of forest bathing or, in Japanese, *shinrin-yuko*.

In previous reviews, the authors reflected upon a development from a culture of practicing immersive nature-experience for the sake of the experience itself toward a more commodified, outcome-driven culture (Sandell, 2004; Schantz and Silvander, 2004). In response to discussions concerning whether this development was within the spirit of immersive nature-experience, Sandell (2004) argued that the continuous growth of immersive nature-experience into other sectors of everyday life should be encouraged and investigated. In the present review, we focused exclusively on health promotion outcomes related to immersive nature-experience within discrete sectors, and the work may thus be considered a continuation and concretization of the outcome-driven focus. While the intermediate health promotion outcomes of immersive nature-experience were discussed in the previous reviews within the context of public health potentials, the main sectors in which immersive nature-experience was practiced were recreational or educational. Perhaps as a consequence of the observed expansion of research and practice of immersive nature-experience, our review differs by including and discussing immersive nature-experience used as an explicit treatment modality, in particular relating to mental and emotional disorders. The present review thus builds on, adds to, and nuances existing insights, rather than presenting a radical paradigm shift in our understanding of the health promotion outcomes of immersive nature-experience.

Direct comparison between health promotion outcomes of immersive nature-experience and non-immersive experience is difficult to make due to the use of varying definitions, categorization, and descriptions of nature contact in the literature (Hartig et al., 2014) as well as pooling of different types of nature-experience in individual reviews (e.g., Twohig-Bennett and Jones, 2018). However, there is empirical evidence to support that the character of the nature contact influences achieved effects. In a recently published meta-analysis (Stevenson et al., 2018), for example, cognitive indicators, e.g., working memory, cognitive flexibility, and attentional control, were found to be significantly higher following direct experience of natural environments compared to indirect exposures, e.g., viewing photos or videos of natural environments. Since our review focused exclusively on direct, immersive contact with natural environments, our results do not allow inferences about this type of nature contact compared with others, e.g., incidental, accumulated exposure due to transport through or views to neighborhood greenery. However, our results suggest that across all outcomes positive effects of immersive nature-experiences occur most consistently for social health [percentage positive (%p) = 68.3%, percentage positive and mixed (%p + m) = 75.6%) compared to mental (%p = 57.6%, %p + m = 70.4%) and physical health (%p = 43.9%, %p + m = 70.2). This suggests that immersive nature-experience might be well-suited for promoting, in particular, social behaviors, skills, and relationships, as well as psychosocial parameters. Since the outcome-level quality assessments were predominantly low, there is some uncertainty regarding the findings. Consequently, subsequent high-quality findings could change the impression made and the knowledge is premature as a background for recommendations for practice.

Although the research connected to physical health was inconsistent, this does not necessarily imply inefficacy. Firstly, the results should be interpreted with attention to the condition that some interventions were compared to active control groups (e.g., Jelalian et al., 2010) and others to waitlist or "treatment as usual" control groups (e.g., Fjørtoft, 2004). Results are influenced by this due to the comparative nature of the research. Secondly, studies in the physical health domain often used many distinct physiological markers to characterize the same phenomenon or closely related phenomena, for example, immune function. If one or more the individual markers were not significantly improved, we categorized the effect as mixed. This might have differentially influenced the physical health domain since many studies in the domain used several markers for the same phenomenon. Mixed findings indicate that positive effects were observed, but interpretation requires caution: Using many markers to address one outcome might be effective for identifying significant effects. In one study (Mao et al., 2012b), for example, six leukocyte subsets were investigated, alongside a number of other physiological indicators. However, in conjunction with small sample sizes, the vast number of variables introduces the risk of finding a significant effect by chance, i.e., type I mistakes. Thirdly, the intermediate health promotion indicator frequently and consistently associated with natural environments, PA (Konijnendijk et al., 2013), was mostly used in observational studies. Furthermore, there is a considerable field of epidemiological research connecting accessibility to green space with PA which was outside the scope of this review. It is well-documented that increased PA and decreased sedentary time reduces obesity, risk of NCDs, such as cardiovascular disease and diabetes, and morbidity (Lee et al., 2012; Ekelund et al., 2016), irrespective of the place where PA takes place. Recently, a connection between PA and cancer has also been established (Monninkhof et al., 2007; Wolin et al., 2009; Speck et al., 2010) and there is sound evidence that PA, in natural outdoor environments or elsewhere, has a direct effect on cognitive function and mental health (Biddle and Asare, 2011). There are indications that PA in natural environments has additional benefits to mental health compared to PA indoors or in urban settings (Bowler et al., 2010), as the present review also suggests. As such, immersive nature-experiences may also contribute to overall PA levels.

Strengths, Limitations, and Future Perspectives

In the following, we discuss strengths and limitations in the reviewed literature. On this basis, we formulate methodological focus points from which the research field may grow further. Although we focused exclusively on immersive nature-experience and distinguished between types of designs; sectors (e.g., recreation, education, or treatment); and health outcomes, the research was spread across diverse intervention characteristics (e.g., activity, pedagogical and instructional approach, duration or type of natural environment); target groups (e.g., adults and children); and control conditions (e.g., no treatment, short nature exposure, and alternative treatment). As such, we did not consider the research suited for meta-analyses, which, we argue, requires more streamlining to avoid simplified conclusions and recommendations. Elsewhere, the inappropriateness of compiling research conducted with adults and children, for example, with the aim to generalize findings without regard to the target group has been addressed (Tillmann et al., 2018). The aim of this review was to accumulate and evaluate the research relating to specific types of nature-based activity. Therefore, we chose to include both child and adult populations and only distinguish between target groups narratively. Subsequent in-depth analyses of the research pertaining to children will follow.

We did not conduct systematic appraisal of risk of bias in the individual studies. Although we assessed studies according to design and apparent methodological issues, potential sources of bias may have been overlooked. For subsets of the review (psychophysiological outcomes and the literature addressing health promotion outcomes for children and adolescents), we have subsequently performed systematic risk of bias and quality appraisals. The systematic assessments made correspond well with the overall narrative assessments made in this review. Furthermore, we included both randomized and non-randomized controlled studies. The latter type of design is by some considered an inappropriate source for inferences relating to effects (Ryan et al., 2013; Gottfredson et al., 2015). We acknowledge the criticisms that can be raised toward this type of design but chose to include this research due to the scarcity of randomized studies. Since the type of design is so widespread in the reviewed literature, results should be interpreted with care and function only as conditional evidence of effects: Findings may be subject to bias and future rigorous studies might provide other results.

Across the types of interventions and outcomes, the quality of the evidence was deemed low; low to moderate; and occasionally moderate. In many studies, sample sizes were small and possibly underpowered which introduces a risk of small-study effects, i.e., inflated effect sizes and false positives as well as negatives (Schwarzer et al., 2015). Most of the studies identified through the literature searches were qualitative (23.3%, $n = 114$), observational, quantitative (34.6%, $n = 169$), or a mix of qualitative and observational, quantitative (10.2%, $n = 50$). However, in comparison to previous reviews that focused exclusively on immersive nature-experience (Sandell, 2004; Schantz and Silvander, 2004), a growth in quantitative, controlled studies may be discernible. However, since the exact numbers of quantitative, controlled studies were not clear in previous reviews, the comparison is speculative. While previous reviews did not apply systematic quality appraisal methods, the quality of the research was considered low (Sandell, 2004; Schantz and Silvander, 2004). In comparison, the quality of the research included in the present review was most often low or low to moderate, and occasionally moderate at an outcome level. As such, it is possible that a development in the quality has occurred. Still, the knowledge base remains only a conditional basis for effect inference and premature as a basis on which to formulate recommendations for practice. It should be emphasized that the intention behind the interventions was not necessarily health promotion, nor for all original studies to provide gold-standard evidence for health promotion effects of the interventions. However, following the broad and holistic conceptualization of health promotion applied in the present review, we deemed the outcomes relevant for health promotion. We appreciate that some of the outcomes could also have been conceptualized in terms of wellbeing or functioning, which in some cases may have been more in line with the original intentions.

Methodological Challenges and Solutions for Future Research

Immersive nature-experience as a subject presents certain core challenges for the conduct of research of the type that is, from a medical, gold-standard point of view, of high quality: (1) immersive nature-experience involves complex interactions between individual subjective experience, activities, pedagogies, and places that are difficult to operationalize and measure in quantitative terms, (2) immersive nature-experiences are often inscribed in real-life contexts in which it is not feasible or desirable to randomize participant allocation, (3) blinding of participants and personnel from group allocation and condition is often not possible, (4) given the complexity of the research subject, transferability between studies and generalizability is challenging. A number of methodological focus points and tools could be used to enhance the quality and transferability of the studies.

The first challenge requires a substantial effort put into formulating a program theory, i.e., identification of intervention input; activities; outputs; intermediate outcomes; and long-term outcomes, and theory of change, i.e., a description of how and why the desired change is expected, pertaining to the specific type of immersive nature-experience and health outcome (Gottfredson et al., 2015). Kuo (2015) and Hartig et al. (2014) reviewed the existing research about nature exposure, in a broad sense, and various health outcomes, and formulated distinct pathways through which exposure to nature could influence health outcomes. The formulated pathways provide handy starting points for formulating theories of change for future studies, but should, at the minimum, be adapted to the specific target group; type of immersive nature-experience; and health outcome. Correspondingly, Hartig et al. (2014) highlighted a need for theory to guide research on which types of nature, and which qualities of those types of nature, are relatively effective for particular outcomes. Based on a review of empirical findings, Kuo (2015) suggested that some pathways are more central or effective than others, and shared **Supplementary Materials** from which additional pathways may be formulated. Here, we would add that the way the natural environments are "activated" and used, and the social or pedagogical processes that it affords, and not only the types and characteristics of the nature, should be considered in theories of change. The first challenge also necessitates the use of process evaluation to describe and, when possible, quantify the actual implementation of the intervention or mechanisms of action. Recent methodological innovations involved monitoring exposure to EOtC by intervention and comparison teachers (Bølling et al., 2018) and highly increased the understanding of the intervention and findings. The monitoring tool did not concern pedagogical practice or qualities of the environments. Future tools could attempt to also address these aspects.

In the reviewed studies, group allocation was often performed by convenience: participants were often recruited amongst individuals who had self-selected into the programs or who had been directed to the program by, for example, their therapist, teacher, or social worker. Furthermore, sociodemographic group comparability, e.g., age, gender, ethnicity, socioeconomic status (SES), or other relevant background variables of intervention and control groups, was seldom thoroughly described and analyzed. In contrast, the randomized controlled trial is commonly considered the gold-standard that provides the highest quality evidence (Gottfredson et al., 2015). While well-conducted randomization is often possible and provides studies with strong internal validity, it may not always be feasible, ethical, or acceptable, for example, when the subjects are very vulnerable or nested in schools or communities (Gottfredson et al., 2015; Frieden, 2017). Alternatively, regression discontinuity designs and comparison time series designs may provide unbiased estimates of intervention effects, where randomization is not practical or possible (Gottfredson et al., 2015). Other types of quasi-experimental designs that maximize feasibility and acceptability for use in prevention research, which in turn increases ecological validity, includes dynamic wait-listed designs, stepped wedge, or regression point displacement designs (Fok et al., 2015; Wyman et al., 2015). We did not identify any such designs amongst the included studies. Furthermore, the usefulness of experimental research may be increased if supported and supplemented by large, high quality cohort studies (Frieden, 2017). This would also contribute to understandings of nature impacts in a life-course perspective (Hartig et al., 2014). We argue, that an increased detail of reporting about, and general attention to, group allocation generation (preferably randomized, when feasible and ethical) and intervention and control group comparability (including, as a minimum, sociodemographic information such as age, gender, ethnicity, and SES) would significantly improve the quality of evidence.

In clinical research, blinding of participants and personnel from treatment is a fundamental tool to avoid performance bias. Elsewhere, the issues relating to blinding in the context of interventions in which environments and visual representations are a core component have been discussed (Brussoni et al., 2015; Ohly et al., 2016). Although full blinding is not possible, researchers could consider blinding participants and personnel from research aims and questions. In general, studies did not address the extent to which participants or personnel were aware of research aims and questions. As such, this may represent the detail of reporting rather than conduct. We suggest that researchers use blinding of participants and personnel from research aims and questions, to the extent that it is ethically valid. Furthermore, we recommend that the manner of blinding is reported clearly.

The fourth challenge requires an increased transparency and detail in reporting that is currently piecemeal in the reviewed literature: in general, activities; pedagogies; and types and qualities of the natural environments of the interventions and programs under investigation were not presented in sufficient detail. This hinders reproducibility and generalizability of the study results, and ultimately accumulation of solid evidence. The issue transferability and generalizability relates to that of cultural specificity in practices of immersive nature-experience and was also identified by Sandell (2004). Given that practices are culturally and geographically bounded, descriptions of these conditions, approaches, and underlying assumptions should to be described carefully. This challenge could be addressed in a systematic manner by utilizing intervention description checklists, for example the Template for Intervention Description and Replication (TIDieR) (Hoffmann et al., 2014). Using such a checklist will provide a transparency about basic intervention and program information pertaining to, for example, intervention delivery, e.g., physical or informational materials and procedures used; provision, e.g., profession, expertise, and specific training of key intervention providers; mode, e.g., face-to-face or group or alone; location, e.g., place and infrastructure; and intensity, e.g., number of sessions, duration, and schedule. Naturally, the checklist is generic in character and, depending on the specific type of activity and the cultural and geographical context, further description is warranted. For example, information about the intended type and actual practice of pedagogical or psychological approach used, e.g., positive psychology or cognitive-therapy, should be included. Likewise, thorough description of the intervention and control environments are also needed, for example, type of landscape, vegetation, elevation, and season.

In addition to these four methodological challenges and suggestions for solutions, the utility of immersive nature-experience as an affordable, upstream health promotion approach (Maller et al., 2006) would be strongly solidified by supplying studies with cost-effectiveness information (Hartig et al., 2014; Gottfredson et al., 2015). In agreement with Hartig et al. (2014), we suggest that future studies consider reporting cost-effectiveness information, or, in the absence of the resource or skill required, the costs related to interventions (Gottfredson et al., 2015).

CONCLUSION

The aim of this systematic review was to summarize and evaluate the evidence for effects of, and associations between, immersive nature experience on mental, physical, and social health. We identified 461 publications including 489 individual studies that met the inclusion criteria. Most studies were qualitative or observational, quantitative. Amongst 133 quantitative analyses in which control groups or conditions had been utilized, we found conditional support for effects of various immersive nature-experience on a range of outcomes: psychological wellbeing ($n = 97$; ≈55% positive; ≈13% mixed; ≈29% non-significant; 2% negative); psychosocial function ($n = 67$; ≈61% positive; ≈9% mixed; ≈30% non-significant); psychophysiological stress response ($n = 50$; ≈58% positive; ≈18% mixed; ≈24% non-significant), and cognitive performance ($n = 36$; ≈58% positive; ≈6% mixed; ≈33% non-significant; 3% negative); and social skills and relationships ($n = 34$; ≈70% positive; ≈7% mixed; ≈22% non-significant). Findings related to outcomes categorized under physical health, e.g., risk of cardiovascular disease, were less consistent ($n = 51$; ≈37% positive; ≈28% mixed; ≈35% non-significant). Walking and seated relaxation in natural environments was most frequently found to enhance aspects of psychological wellbeing, reduce psychophysiological stress, and enhance cognitive performance. Intense and demanding expeditions in wild or urban nature or primitive camp-based experiences targeted toward behavioral change, or personal or social development, promoted psychosocial indicators, the ability to engage in social contexts, cooperation skills, family development, behavior (e.g., substance abuse and crime) across a range of populations.

Across the types of interventions and outcomes, the quality of the evidence was deemed low and occasionally moderate and therefore only serves as a conditional basis for inferences about effects. Based on the main reasons for considering the quality of the evidence low, we discussed four core methodological challenges identified in the reviewed literature and provided tools to address these challenges in future studies: Given the complexity of pathways between immersive nature-experience and health outcomes, studies should develop and be guided by theories of change and develop logic models for the individual immersive nature-experience and health outcome under question. Furthermore, an increased detail of reporting about, and general attention to, group allocation generation (randomized, when ethical and feasible); intervention and control group comparability (including sociodemographic information); blinding (participants, personnel, and outcome assessors); and recruitment and sampling would increase interpretability and quality of the research. Finally, further use of process evaluation and systematic intervention description is warranted. An additional focus point for future research that could provide a strong argument for immersive nature-experience as a health promotion initiative involves reporting costs related to the intervention and, when possible, cost-efficiency.

AUTHOR CONTRIBUTIONS

LM, PB, and EM designed and planned the systematic review. LM, EK, and RH performed electronic and supplementary literature searches. All authors contributed to literature screening, full-text eligibility assessments, and data extraction. LM and EK analyzed the literature and wrote up an early paper draft. All authors contributed to the final manuscript.

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SUPPLEMENTARY MATERIAL

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The Application of Wearable Technology to Quantify Health and Wellbeing Co-benefits From Urban Wetlands

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Improved nature provision in urban environments offers great potential for achieving both biodiversity conservation and public health objectives. Yet there are few experimental studies that address links between specific natural environments and physiological and/or psychological changes that could contribute to the health and wellbeing co-benefits of urban nature. In addition, relative to green space, the salutogenic impact of aquatic environments are understudied. Here, we present a feasibility study examining the use of low-cost wearable technology to quantify the psychophysiological effects of short-term exposure to urban wetlands. The study took place at the WWT London Wetland Centre, which is characterized by its contrasting biodiverse wetland habitat and surrounding urban setting. Thirty-six healthy participants experienced counterbalanced exposures to an indoor space, a wetland, an urban site. We continuously recorded electroencephalographic (EEG) data and real-time physiological stress responses; with additional monitoring of post-exposure self-reported mood states. We found a significant effect of site on mean resting heart rate (HR), with increased HR in the urban setting, although this was only observed in participants with pre-existing high stress. We found no significant differences in other measures of physiological stress responses (heart rate variability and electrodermal activity). The EEG data showed modulation of high beta band activity only in the wetland setting, potentially related to changes in attention. However, the EEG findings were confounded by low quality signals and artifacts caused by movement and environmental interference. Assessments of self-reported mood states demonstrated an increase in positive feelings in the wetland setting. A pronounced decrease in negative feelings in the wetland setting was observed in stressed individuals only. Our results suggest that pre-existing stress levels may be an important modulator of the salutogenic effect of blue-green space. We provide partial support for the hypothesis that exposure to blue-green space promotes stress recovery and for the use of low-cost psychophysiological measurements to quantify the potential stress-reducing effects of blue–green space exposure in urban dwellers. Further technological refinement is required for this approach to become a viable tool to support evidence-based decision-making for public health and green/blue space provision.

Keywords: blue–green space, wellbeing, stress, salutogenesis, physiology, electroencephalogram (EEG), psychological restoration, blue–green infrastructure

INTRODUCTION

It is estimated that by 2050 two-thirds of the global human population will live in urban centers (United Nations Department of Economic and Social Affairs, 2014). Future urban environments are predicted to face significant challenges associated with increased air and water pollution, altered water regimes, diminished water quality, greater extremes of flood and drought (Taylor et al., 2004; Miller and Hutchins, 2017) and urban heat island effects (Levermore et al., 2018). Therefore the trend toward urbanization, especially in the context of climate change, poses significant challenges to the many activities that influence people's health and wellbeing (HWB), including urban planning, infrastructure development, employment, food security and healthcare. Widespread adoption of blue-green infrastructure (BGI) within growing and emerging urban environments has the potential to secure and create ecosystem services that counter these adverse biophysical impacts of urbanization (Voskamp and Van de Ven, 2015). BGI may also provide socio-cultural and public health co-benefits through their association with increased social inclusion, interaction, and cohesion (e.g., Cohen et al., 2008; Francis et al., 2012; Hartig et al., 2014; Jennings et al., 2016; Jennings and Bamkole, 2019), improved public safety (e.g., Branas et al., 2011) and enhanced quality of life (e.g., Thompson et al., 2014; Aspinall et al., 2015; McCracken et al., 2016; Mensah et al., 2016).

In recent years, numerous studies have reported on the role of exposure to natural environments in both disease prevention and salutogenesis, the latter referring to the promotion of HWB rather than simply the absence of disease (for a recent review, see Kondo et al., 2018a). The literature suggests several possible pathways by which exposure to natural environments may deliver HWB benefits (Hartig et al., 2014; Kuo, 2015). Two prominent and complementary frameworks are the Stress Recovery Theory (SRT; Ulrich, 1983) and the Attention Restoration Theory (ART; Kaplan, 1995), both of which posit that natural environments have restorative potential, because they moderate physiological arousal or reduce mental fatigue (Berto, 2014). It is hypothesized that this reduction in psychological and physiological stress promotes HWB benefits.

Different types and qualities of natural environments influence HWB in different ways and extents (Hartig et al., 2014; South et al., 2015; Wheeler et al., 2015). Research into aquatic environments or 'blues spaces,' defined broadly as any environment predominantly comprising a natural or human-modified water feature, has primarily focused on coastal environments (e.g., Miller et al., 2012; Wheeler et al., 2012; White et al., 2013). Despite being prominent environmental features, freshwater blue spaces, such as lakes, ponds, rivers, streams and other wetlands, are largely understudied (White et al., 2010; Foley and Kistemann, 2015), particularly in urban areas. Despite insufficient research and substantial heterogeneity across studies, systematic reviews of the literature point to an overall positive association between exposure to blue space and improved mental health, wellbeing and the promotion of physical activity has been identified (Gascon et al., 2015, 2017). Research in Germany and Hong Kong supports the delivery of salutogenic effects by blue space provision in large cities (Völker et al., 2018; Garrett et al., 2019). In the United Kingdom, a region-wide, cross-sectional survey suggests visits to freshwater blue space promotes social interaction and conveys psychological benefits (de Bell et al., 2017). Recently announced research programs in Europe will further aim to map and quantify the impacts of urban blue infrastructure (Grellier et al., 2017). A few experimental studies have attempted to isolate the effects of blue space as compared to green space by exposing participants to photographs as a proxy for natural environments. These findings do suggest that blue space has enhanced capacity to promote psychological restoration relative to green space (e.g., White et al., 2010; Seresinhe et al., 2015; Grassini et al., 2019).

Historically, some sectors of the nature conservation movement have promoted approaches to preserving natural environments by excluding people from them or restricting access through the establishment of protected areas (Brockington and Igoe, 2006). This conservation method stands in stark contrast to the more recent narrative that favors (re)connecting people with high quality and/or extensive natural environments to foster resilience in both ecosystems and human communities (e.g., Wood et al., 2017). Research in the health sciences and increasingly from conservation biology, environmental psychology, environmental education and sustainability science further supports the beneficial effects of (re)connecting people with nature to enhance human HWB and promote the uptake of pro-environmental attitudes and behaviors (Ives et al., 2018; Rosa et al., 2018). Despite a growing interest in understanding how exposure to natural environments might be leveraged to achieve the goals of both conservation and public health (Bottrill et al., 2014; Milner-Gulland et al., 2014; Lovell et al., 2015), progress in this field has been limited by the complexities of human–environment interactions and a lack of understanding of the mechanisms that support the delivery of benefits (Hartig et al., 2014; Shanahan et al., 2015; Dadvand et al., 2016). Retrospective and observational studies dominate the literature and few studies have focused specifically on inland aquatic environments. Laboratory-based, but in particular 'natural' experimental studies have been proposed as an important step toward developing a deeper understanding of how natural environments might be leveraged to deliver multiple co-benefits (Frumkin et al., 2017; Gascon et al., 2017). To this end, innovative methods are required to accurately capture physiological and psychological responses *in situ*, as the experience unfolds (Frumkin et al., 2017). In recent years, we have seen a significant rise in the popularity and quality of a wide range of commercially available wearable technologies that allow for continuous monitoring of physiological signals (Bunn et al., 2018). As they are minimally obtrusive and offer opportunity to observe individuals in 'naturalistic' outdoor experiments, these devices are increasingly used in research applications. A small number of studies have used mobile devices to monitor responses to urban versus natural environments (Kondo et al., 2018b but see: Aspinall et al., 2015; Neale et al., 2017; Tilley et al., 2017; Olszewska-Guizzo et al., 2018) but – to our knowledge – none have specifically focused on blue space.

In this study we take advantage of the unique setting of the WWT London Wetland Centre, a 42 hectare constructed urban wetland in West London, created and managed by the Wildfowl & Wetlands Trust (WWT)[1] to experimentally test, for the first time, the salutogenic potential of urban wetlands. As a wetland conservation charity, WWT seeks to provide co-benefits to biodiversity and to the broader public through recreation and education activities at its wetland conservation sites. WWT London Wetland Centre visitor feedback frequently describes the site as an 'oasis' within the metropolis of London (**Figure 1**). To explore this further, WWT engaged in a collaboration with Imperial College London to investigate and develop metrics for monitoring and evaluating the potential HWB benefits delivered to visitors. Specifically, we aimed to critically evaluate the feasibility of low-cost wearable technology to complement subjective measures of HWB. We report on a pilot study implementing a commercially available EEG system and photoplethysmography (PPG) device to detect differences in brain activity and physiological stress as a short-term wetland visitor experience unfolded. This represents an important advance upon previous research in this field, which is typically limited to broad-scale epidemiological or laboratory-based experiments using only proxies for real blue space exposure. The findings are intended to inform the design, monitoring, evaluation and improvement of WWT activities aimed at delivering HWB benefits to communities and visitors, and, more generally, to support evidence-based policy-making in urban planning (Wildfowl & Wetlands Trust [WWT], 2017).

FIGURE 1 | An image of the study site, featuring the WWT London Wetland Centre and the urbanized area of West London (Barnes). Photograph credits: Sam Stafford (WWT).

MATERIALS AND METHODS

Participants

We recruited 36 participants for this study, the majority of which were contacted through a social corporate responsibility scheme which allows local professionals to volunteer for WWT during normal work hours. Just over half (53%, n = 34) had never visited the wetland center before. Of the participants who gave responses, 83% (n = 29) were not WWT members or affiliates, while 68% percent (n = 25) were not members of other conservation charities. Overall, the majority of our sample was unfamiliar with wetland conservation prior to participating in the study. All participants were screened against exclusion criteria, i.e., the presence of neurological conditions or injuries, psychiatric disorders, cardiovascular disease, taking of prescription or over-the-counter medicines, and any departure from normal or corrected-to-normal eyesight or hearing. This resulted in exclusion of n = 2 participants. Written prior and informed consent was obtained from each participant.

Study Site

The study took place in and around the WWT London Wetland Centre located in Barnes, West London, which was created through the conversion of four disused Victorian reservoirs into a range of biodiverse wetland habitats. The WWT London Wetland Centre consists of a visitor center (including a café and education center), an area of living collection of wetland birds and mammals, and surrounding managed wetland habitats. The latter carries the Site of Special Scientific Interest (SSSI) designation due to its national importance for UK breeding birds in lowland open waters and for its assemblages of non-breeding gadwall (*Anas strepera*) and shoveler (*Anas clypeata*). This site was selected for this experiment because of its unique location (**Figure 1**) that enables a quick transition between exposure to a species-rich SSSI wetland and a typical urban setting. The sites were selected with the intention of achieving maximal contrast between the urban and wetland environment in order to maximize the potential of detecting differences in psychophysiological and subjective responses from short exposures. Limitations around experimental practicalities were also taken into account i.e., the need to reduce distance walked and time in the experiment.

[1] wwt.org.uk

Control Site

A multipurpose function room at WWT London Wetland Centre (51°28′37.9′′N 0°14′09.2′′W) was used as a control setting for baseline measures of PPG and EEG (**Figure 2A**). The room contents consisted of chairs, tables, a TV and modest décor. Its use as a function/class room enabled us to isolate participants from center visitors and external noise, thus creating a relatively low stimuli environment. It is favorably located between the wetland and urban sites.

Wetland Site

The control site is situated in the visitor center area (51°28′47.2′′N 0°14′08.5′′W), which includes the café, shop and education center of the WWT London Wetland Centre site. Adjacent is a captive animal area and beyond the captive area is 'Wildside': a managed 'natural' wetland area (**Figure 2B**). We were cognizant of the need to keep distance walked to minimum because of headset discomfort and experimental fatigue and also because our interest was in seated/resting responses to urban and natural wetland environments. For the latter reason, both the wetland and urban sites were chosen because they featured permanent benches and represented 'real-world' resting spots. The wetland site was chosen because it was the first bench within 'Wildside' with a blue/green vista overlooking water.

Urban Site

The study area (WWT London Wetland Centre) was chosen to create maximally opposing sensory experiences and to test differential responses to these environments. With similar consideration to the wetland site, the urban site (51°28′31.3′′N 0°14′21.3′′W) was chosen because it was the first suitable urban bench outside the Centre. Suitability was judged by the number of features present at this site that are typical of busy urban settings e.g., a traffic intersection, traffic lights, a pedestrian crossing, passers-by, shops, and cafes.

FIGURE 2 | Composite image illustrating the exposure conditions, i.e., the control room where baseline measures were taken **(A)**, and representative images of the wetland setting **(B)** and the urban setting **(C)**, and aerial views of the walk to each site from the control room. Photograph credits: Sam Stafford and Kate Smith (WWT).

Procedure

The study was conducted between the 14th July and 23rd August 2017. Prevailing weather conditions were recorded for each participant session (cloud cover, air temperature, wind speed humidity using UK Met Office data[2]). The level of other potentially confounding variables (e.g., air traffic) was also recorded. Over the 6 week testing period no sessions were canceled due to adverse weather. Participants attended their allocated session individually, with scheduled start times at 9am, 12pm, or 2pm. Upon arrival participants were greeted by a researcher and shown to the visitor center. We first conducted brief, semi-structured interviews to explore participants' motivations to take part, expectations about the experiment, anticipated benefits, pre-existing knowledge of the site, any formal or informal affiliation to WWT (e.g., member, donor, volunteer), support for other conservation charities, and their understanding of the aims and procedures. Participants were also asked how they felt in the moment, and whether that was a departure from their regular mental and/or physical state. Following the interview, participants were asked to complete a set of questionnaires to obtain demographic information (age, gender, employment status), and an assessment of relevant psychological variables including life stress, recent levels of depression, anxiety and stress, and participants' sense of connectedness with nature to provide an assessment of participants recent exposure and response to stressors. The in-depth interview data were intended to provide qualitative contextual information, but a report on this is beyond the scope of the current study.

The experimental setup consisted of a wristband measuring real-time physiological data and a mobile EEG device [for details, see Depression, Anxiety Stress Scale (DASS-21)]. Fitting the measurement equipment took approximately 15 min. Following calibration, EEG and physiological data were continuously recorded for the full duration of the experiment. Participants remained seated in the indoor control room for 10 min to obtain stable baseline readings (**Figure 2A**). For the outdoor sections of the experiment, participants carried a light rucksack with the EEG data acquisition laptop. A researcher accompanied the participant to each site. Walking distances between the control and the urban and wetland setting were 390 and 430 m, respectively (**Figures 2B,C**), the terrain was flat. Participants were then asked to sit for 10 min on a permanent bench at each site, with the researcher retiring out of sight for all exposure periods. For all three exposures, and for the full 10 min, participants were instructed to relax, remove the backpack, remain seated and to take in their surroundings, but not to close their eyes. At the end of the 10 min exposure, participants were asked to complete a self-report survey assessing mood states. After completing the

[2]www.metoffice.gov.uk

baseline, urban and wetland site exposures, a short debriefing session followed. We were specifically interested in whether participants showed a stated preference for the urban or the wetland site and whether they had experienced any physical (e.g., from wearing the equipment) or psychological discomfort or distress that might confound the outcome measures.

The study had a repeated measures design, with three exposure conditions/sites: indoor (control), urban and wetland. Condition order of the urban and wetland sites was counterbalanced between participants; the control condition was always administered first.

Baseline Assessments

The Holmes and Rahe Stress Inventory

The Holmes & Rahe Stress Inventory, also known as the Social Readjustment Rating Scale (Holmes and Rahe, 1967) comprises a checklist of significant life events. Respondents are asked to indicate the number of events they have experienced in the last year. Frequencies of occurrence are multiplied by the event's 'Life Change Units' as an indicator of severity. The total summed scores is indicative of overall stress and associated with the risk of developing stress-related health problems.

Depression, Anxiety Stress Scale (DASS-21)

We used the 21-item version of the Depression, Anxiety and Stress Scale (DASS-21; Henry and Crawford, 2005) to measure reported signs of depression (expressed as dysphoria, hopelessness, devaluation of life, self-deprecation, lack of interest/involvement, anhedonia, or inertia), anxiety (expressed as autonomic arousal, muscle tension, situational anxiety, and subjective experience of anxious affect) and stress (expressed as difficulty relaxing, nervous arousal, and being easily agitated, irritable, over-reactive and impatient). Respondents are asked to rate each of the 21 items (e.g., "I found it hard to wind down") on a 4-point Likert scale, indicating the extent to which they have experienced that state over the past week. Scores for depression, anxiety and stress are calculated by summing the scores for the relevant items. The DASS-21 has high internal consistency and yields meaningful discriminations in a variety of settings. We used the UK normative data published by Henry and Crawford (2005) to categorize participants as having either above or below average stress levels.

The Nature Relatedness Scale

The Nature Relatedness Scale (Nisbet et al., 2009) is a 21-item instrument used in research on sustainability and wellbeing, serving as a measure of individual differences in connectedness with nature. Comprising of three scales, the NR-self (8 items), the NR-perspective (7 items) and the NR-experience (6 items), it provides a measure of the respondent's internalized identification with nature (i.e., feelings of personal connectedness and meaning), their external nature-related world view (i.e., a sense of agency concerning our impact on the environment) and their physical familiarity with the natural world (i.e., a desire to interact and actively engage with the natural world). High scores are associated with increased concern for the environment.

Outcome Assessments

Real-Time Physiological Stress Measures

Cardiovascular and electrodermal activity metrics are commonly used to assess and monitor the relative activity of the sympathetic and parasympathetic branches of the autonomic nervous system, which are respectively associated with states of threat (fight or flight response) and calm (rest and digest). These metrics can therefore be interpreted as indicators of physiological and psychological stress (Camm et al., 1996; Jacobs et al., 2012; Kondo et al., 2018b). We used an Empatica E4 wristband (Garbarino et al., 2014) to obtain continuous physiological responses from the participants. The wristband includes a photoplethysmography (PPG) sensor to measure blood volume pulse (BVP) which is used to derive heart rate (HR) and heart rate variability (HRV), and an electrodermal activity (EDA) sensor to measure changes in skin conductance. The wristband was attached to the non-dominant hand of the participant, with PPG and EDA data recorded at 64 and 4 Hz respectively.

Heart rate

Heart rate increases as a result of both physical exertion and psychological stress. Evidence suggests that HR responds to acute environmental stimuli (Kjellgren and Buhrkall, 2010; Park et al., 2010; Song et al., 2013). From the continuous HR recording, we calculated the mean HR in each setting (control, wetland and urban), expressed in beats per minute (bpm). The analysis window was restricted to the central 8 min of the exposure period. Standard HR recovery testing measures HR from *peak* exercise to 2 min post-exercise (Cole et al., 1999; Shetler et al., 2001). For moderate exercise (walking), we eliminated the first and last minute to minimize the impact of cardiovascular recovery from the walk to the site, and the effects of increased movement observed in participants toward the end of the exposure period.

Heart rate variability

A healthy heart is not a metronome (Shaffer et al., 2014) and HRV represents the fluctuation in the time intervals between adjacent heartbeats. Typically, higher HRV values are associated with improved physiological health and self-regulatory capacity or resilience (Carney et al., 2005; Thayer et al., 2010). HRV may also be associated with psychological processes linked to prefrontal brain function, such as attention and emotion (McCraty and Shaffer, 2015). We used Kubios HRV Standard 3.1.0 (Tarvainen et al., 2008) to process the PPG data and derive HRV parameters, applying threshold-based correction to remove artifacts and ectopic beats by comparing inter-beat interval values (the time period between successive heartbeats; IBI) against a local average interval. We then used an advanced de-trending method based on smoothness priors regularization (Tarvainen et al., 2002). Applying a time-varying high-pass filter the data are smoothed to remove IBI time series non-stationarities. Samples with artifact correction $>15\%$ were discarded to minimize the impact of artifacts on analysis results (Tarvainen et al., 2008). Consequently, only 12 participants with good quality data for all three conditions were retained (**Supplementary Table 1**). Following the convention for short-term recording (Camm et al., 1996), we selected 5 consecutive minutes of signal 3 min into each measurement period, thereby selecting a central portion for each period. This selection process was repeated for each participant and each condition.

Typically, HRV is analyzed as a time-domain and/or frequency-domain signal. The former quantifies the variability in measurements of the IBI. Computationally more straightforward, it is more consistently applied in the existing literature (Michael et al., 2017) compared with the frequency-domain measurements that estimate the distribution of absolute or relative power into various frequency bands.

We applied the following time-domain metrics suitable for characterization of HRV based on short (i.e., 5 min) epochs: the root mean square of successive differences of the inter-beat intervals (RMSSD), the number of adjacent NN intervals that differ from each other by more than 50 ms (NN50) and the Triangular Interpolation of the NN Interval Histogram (TINN). Note that NN intervals refer to the intervals between 'normal' peaks, i.e., excluding abnormal beats due to measurement artifacts. For the frequency-domain, we employed the most common method to calculate HRV spectra, i.e., a Fourier transform, to derive the primary components: the low frequency (LF, 0.04–0.15 Hz) and high frequency (HF, 0.15–0.40 Hz) spectra. For further analysis, we opted to transform the data using the natural logarithm to yield an approximately normal distribution (Michael et al., 2017).

Electrodermal activity

The Empatica E4 sampled EDA at 4 Hz, and skin conductance (SC) was measured in micro-Siemens (μS). Due to variation in the length of EDA readings across participants, analysis windows were standardized by removing the first minute of data. The subsequent 8 min were used in the analysis.

Continuous Decomposition Analysis (CDA) was performed on EDA data in Ledalab (Benedek and Kaernbach, 2010) to decompose SC data into tonic (skin conductance level; SCL) and phasic (skin conductance response; SCR) components (Dawson et al., 2007). Event markers were imported from Empatica E4 wristbands to determine the central 8 min SC analysis window for each exposure session. For the purposes of this study, two measures representing tonic and phasic activity were used; the mean tonic activity within a treatment window, and the number of significant SCR events, respectively.

Electro-Encephalography (EEG)

We used an Emotiv® EPOC+ EEG system to obtain brain electrical activity measurement non-invasively through the scalp. The EPOC+ has 14 channels in the international 10–20 position system (AF3, AF4, F3, F4, F7, F8, FC5, FC6, T7, T8, P7, P8, O1, and O2), with P3 and P4 as reference electrodes. To prevent electrode dehydration we added 5% glycerol to the saline solution before wetting the electrodes. Electrodes were checked for contact quality, signals were sampled at 128 Hz per channel and sent via Bluetooth to a portable laptop computer. EEG data was pre-processed using EEGLAB (Delorme and Makeig, 2004). Data from each participant were imported and analyzed individually. In EEGLAB the 14 data, and 1 marker (events), channels were defined and mapped according to the international 10–20 position system (see above). The continuous EEG signal was filtered with high and low band-pass frequencies of 0.16 and 42 hz, and then re-referenced to the average reference in EEGLAB. Using event markers the signal was segmented into control, urban and wetland epochs with extreme artifacts and poor data regions rejected through visual inspection and ICA. A Fast Fourier Transform (FFT) was applied, normalized by the number of data points of the processed recording, to extract component frequencies for all 14 sensor location on the headset. Given that the Emotiv® has only 14 channels and the data sample rate is only 128 Hz, we calculated a global average for each frequency band (e.g., see: McMahan et al., 2015). Root mean square (RMS) values were obtained for each segment of data corresponding to the exposure conditions/sites (control, wetland and urban). Using an in-house MATLAB script, we extracted RMS for delta (0.5–4 Hz), theta (4–8 Hz), alpha (9–13 Hz), low beta (13–19 Hz), high beta (21–27 Hz), frequencies, each associated with different mental states and levels of consciousness (**Table 1**). For the analysis of the EEG data, we therefore obtained one mean value per frequency band for each individual and each site. To standardize the data before statistical analysis, we employed a min-max scaling procedure. Following inspection of the boxplot for the different EEG frequency bands, we eliminated 30 data points as outliers (**Supplementary Figure 1**).

Self-Reported Mood States

To capture mood state changes following exposure to the different environments, participants were asked to complete the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) following each 10 min exposure session. The PANAS consists of two 10-item scales measuring positive and negative mood states. Items are rated on a 5-point scale from "not at all" to "very much." Summed scale scores reflect independent dispositional dimensions. A high score on the negative affect scale indicates subjective distress and un-pleasurable engagement, and a low score indicating the absence of these feelings. High scores on the positive scale are associated with enthusiasm and alertness, indicating a pleasurable engagement with the environment whereas low scores are associated with lethargy and sadness. The PANAS has been shown to produce a reliable

TABLE 1 | Mental states associated with different EEG frequencies (based on: Nunez PL, Srinivasan R. Electric fields of the brain: The neuro-physics of EEG, 2nd Edition. Oxford University Press, Inc., New York, NY, United States, 2006).

Frequency	Associated with. . .
Delta (0.5 – 4 Hz)	• Adult slow-wave sleep • States of altered consciousness
Theta (4 – 8 Hz)	• Drowsiness or idling • Deep meditation and daydreaming • Memory encoding
Alpha (9 – 13 Hz)	• Relaxation, reflection, resting state • Creative and artistic processes
Low beta (13 – 19 Hz)	• Concentration, alertness • Task-related activity
High beta (21 – 27 Hz)	• Increases in directed attention • Anxious thought, excitement

and valid measure of positive and negative mood states in a non-clinical British sample (Henry and Crawford, 2005).

Statistical Analyses

We report descriptive statistics for the sample's demographic characteristics and baseline assessments of stress levels and nature-relatedness. To explore the influence of demographic differences on baseline indicators of stress and nature-relatedness, we conducted t-tests (assessing gender differences) and examined Pearson correlations (assessing associations with age). We created separate general linear models for each of the continuous outcome measures, with Site (control, urban and wetland) as the within-subjects factor, while controlling for Site Order, which was entered as a between-subjects factor. To account for individual differences that could impact physiological responses, we also controlled for current (self-reported) levels of stress. For this purpose, we classified participants into 'self-reported low stress' and 'self-reported high-stress' groups on the basis of their DASS-21 stress score relative to published UK population mean scores (Henry and Crawford, 2005), and included this as a between-subjects factor. For the EEG analysis, we included frequency band (alpha, high-beta, low-beta, theta, and delta) as an additional within-subjects factor.

RESULTS

Demographic Data and Baseline Assessments

Participants were on average 41 years of age (*SD* = 10.28). Women were slightly over-represented in the sample (61.8%) compared with men (38.2%). Descriptive statistics for the baseline assessments are summarized in **Table 2**. On average, participants' life stress scores were relatively elevated, which is associated with increased risk of developing stress-related health conditions. A minority (15.2%) of the sample fell into the 'low risk' category (scores < 150), while almost half (48.5%) of the sample was classified as being at moderate risk (scores 150–300), and a significant proportion (36.4%) were at high risk (scores > 300).

The DASS-21 is indicative of self-reported stress, anxiety and depression in the last week. In relation to relevant UK-based norm scores, the sample scores (on average) fell within the 58–68th percentile for Depression, the 54–69th percentile for Anxiety and the 60–69th percentile for Stress (Henry and Crawford, 2005). Participants also reported high levels of nature relatedness, with average scores similar to those who report 'seeing themselves as an environmentalist' (Nisbet et al., 2009). Additional analyses with respect to demographic (age, gender) differences in these baseline measures are reported in **Supplementary Tables 2, 3** and **Supplementary Figure 2**.

Exposure Effects on Psychophysiological Measures

Heart Rate

There was a significant effect of Site on mean HR, $F(2,56) = 3.703$, $p = 0.031$, $\eta^2 = 0.117$, and a significant interaction between Site and Stress Level, $F(2,56) = 4.848$, $p = 0.011$, $\eta^2 = 0.148$, but no interaction effect between Site and Site Order, $F(2,56) = 0.261$, $p = 0.771$, $\eta^2 = 0.009$. Neither the main effect of Site Order, nor Stress Level was significant, $F(1,28) = 0.846$, $p = 0.366$, $\eta^2 = 0.029$ and $F(1,28) = 0.215$, $p = 0.647$, $\eta^2 = 0.008$, respectively.

To clarify the interaction effect, we conducted a simple effects analysis, which demonstrated no significant differences between sites for 'self-reported low stress' individuals, $F(2,27) = 0.399$, $p = 0.675$, $\eta^2 = 0.029$, but a significant effect of Site in 'self-reported high stress' individuals, $F(2,27) = 6.045$, $p = 0.007$, $\eta^2 = 0.309$. Pairwise comparisons indicated increased HR in the urban setting compared with both the wetland ($p = 0.030$) and the control setting ($p = 0.005$; corrected for multiple comparisons) (**Figure 3**).

Heart Rate Variability

We found no significant differences between the exposure conditions on any of the time-domain HRV metrics. There was no significant main effect of Site on RMSSD, $F(2,22) = 0.711$, $p = 0.502$, $\eta^2 = 0.061$, and no effect of Site Order, $F(1,11) = 0.29$, $p = 0.867$, $\eta^2 = 0.003$, or Stress Level, $F(1,11) = 0.769$, $p = 0.399$, $\eta^2 = 0.065$. We observed no significant interaction effects between Site and Site Order, $F(2,22) = 1.285$, $p = 0.297$, $\eta^2 = 0.105$, or Site and Stress Level, and $F(2,22) = 1.781$, $p = 0.192$, $\eta^2 = 0.139$.

Similarly, the main effect of Site on NN50 was not significant, $F(2,22) = 0.775$, $p = 0.481$, $\eta^2 = 0.064$. There was no significant main effect of either Site Order, $F(1,11) = 0.576$, $p = 0.464$,

TABLE 2 | Descriptive data for the baseline psychological measurements.

		N	Scale scores			
			Sample minimum	Sample maximum	Mean	*SD*
Holmes-Rahe social readjustment rating scale		33	39	1032	287.18	204.19
DASS-21	Depression subscale	33	0	15	2.48	3.15
	Anxiety subscale	33	0	8	1.39	1.78
	Stress subscale	33	0	18	5.30	4.30
Nature relatedness scale	Self	34	21	39	31.26	4.74
	Perspective	34	19	34	28.76	4.00
	Experience	34	10	30	23.06	4.34

$\eta^2 = 0.050$, or Stress Level, $F(1,11) = 1.317$, $p = 0.275$, $\eta^2 = 0.107$. None of the interaction effects were significant, for Site and Site Order, $F(2,22) = 0.669$, $p = 0.522$, $\eta^2 = 0.057$; for Site and Stress Level, $F(2,22) = 1.544$, $p = 0.236$, $\eta^2 = 0.123$.

The main effect of Site on TINN was not significant, $F(2,22) = 0.991$, $p = 0.387$, $\eta^2 = 0.083$. There was no significant main effect of either Site Order, $F(1,11) = 0.551$, $p = 0.474$, $\eta^2 = 0.048$, or Stress Level, $F(1,11) = 0.603$, $p = 0.454$, $\eta^2 = 0.052$. None of the interaction effects were significant, for Site and Site Order, $F(2,22) = 0.158$, $p = 0.782$, $\eta^2 = 0.014$; for Site and Stress Level, $F(2,22) = 0.459$, $p = 0.638$, $\eta^2 = 0.040$.

With respect to the frequency-domain, we did not find a significant main effect of Site on the Low Frequency signal, $F(2,22) = 0.156$, $p = 0.857$, $\eta^2 = 0.014$, nor the High Frequency signal, $F(2,22) = 2.614$, $p = 0.096$, $\eta^2 = 0.192$. Site Order seemed to have a marginally significant effect on the Low Frequency signal, $F(1,11) = 4.206$, $p = 0.065$, $\eta^2 = 0.277$, but not on the High Frequency signal, $F(1,11) = 0.216$, $p = 0.651$, $\eta^2 = 0.019$. No significant effects were observed of Stress Level on the Low Frequency or the High Frequency signal, $F(1,11) = 0.529$, p = 0.482, $\eta^2 = 0.046$ and $F(1,11) = 0.656$, $p = 0.435$, $\eta^2 = 0.056$, respectively. The interaction effect between Site and Site Order was not significant for the low Frequency signal, $F(2,22) = 0.291$, $p = 0.750$, $\eta^2 = 0.026$, nor for the High Frequency signal, $F(2,22) = 0.255$, $p = 0.777$, $\eta^2 = 0.023$. Finally, no significant interaction was observed between Site and Stress Level for the Low Frequency signal, $F(2,22) = 0.385$, $p = 0.685$, $\eta^2 = 0.034$, nor for the High Frequency signal, $F(2,22) = 2.610$, $p = 0.096$, $\eta^2 = 0.192$.

Electrodermal Activity

We found no significant effects on the phasic EDA activity (the number of significant skin conductance responses, nSCR), nor on the measure of tonic EDA activity.

The main effect of Site on nSCR was not significant, $F(2,58) = 0.414$, $p = 0.663$, $\eta^2 = 0.014$. There was no significant main effect of either Site Order, $F(1,29) = 0.638$, $p = 0.431$, $\eta^2 = 0.022$, or Stress Level, $F(1,29) = 0.821$, $p = 0.372$, $\eta^2 = 0.028$. The interaction effects were not significant, for Site and Site Order, $F(2,58) = 1.068$, $p = 0.350$, $\eta^2 = 0.036$; or for Site and Stress Level, $F(2,58) = 0.657$, $p = 0.522$, $\eta^2 = 0.022$.

For the within-subjects effects on tonic EDA, we report Greenhouse–Geisser correct results, as Mauchley's test of sphericity was significant [$W = 0.382$, 2(2) = 26.96, $p < 0.001$]. There was no significant main effect of Site, $F(1.24,35.84) = 0.119$, $p = 0.785$, $\eta^2 = 0.004$. There was no significant main effect of either Site Order, $F(1,29) = 0.325$, $p = 0.573$, $\eta^2 = 0.011$, or Stress Level, $F(1,29) = 0.030$, $p = 0.865$, $\eta^2 = 0.001$. The interaction effects were not significant, for Site and Site Order, $F(1.24,35.84) = 0.421$, $p = 0.563$, $\eta^2 = 0.014$; for Site and Stress Level, $F(1.24,35.84) = 0.671$, $p = 0.449$, $\eta^2 = 0.023$.

EEG Response

For the effect of Frequency Band, we report Greenhouse–Geisser correct results, as Mauchley's test of sphericity was significant [$W = 0.145$, 2(9) = 18.20, $p = 0.035$]. There was no significant main effect of Site on the RMS of the EEG signal, $F(2,22) = 0.656$, $p = 0.529$, $\eta^2 = 0.056$, and there were no systematic differences between the Frequency Bands, $F(2.28,25.02) = 0.418$, $p = 0.795$, $\eta^2 = 0.037$. Site Order also did not affect the EEG signal, $F(1,11) = 0.614$, $p = 0.450$, $\eta^2 = 0.053$ and neither did Stress Level, $F(1,11) = 1.667$, $p = 0.223$, $\eta^2 = 0.132$. However, of key interest is the interaction effect between Site and Frequency Band, which indicates differential environmental effects depending on the EEG band, $F(8,88) = 2.195$, $p = 0.035$, $\eta^2 = 0.166$. Simple effects analysis showed that EEG responses varied by site only in the High Beta band, $F(2,10) = 6.320$, $p = 0.017$, $\eta^2 = 0.558$. Significantly stronger signals were observed in the wetland versus the urban setting ($p = 0.015$), whereas they only marginally differed from the control setting ($p = 0.076$), and the urban and control setting also did not differ ($p = 0.654$) (**Figure 4**). None of the other frequency bands showed any differences in EEG signal [low-beta, $F(2,10) = 2.482$, $p = 0.133$, $\eta^2 = 0.332$, alpha, $F(2,10) = 0.691$, $p = 0.524$, $\eta^2 = 0.121$, Theta, $F(2,10) = 0.264$, $p = 0.773$, $\eta^2 = 0.050$ and Delta, $F(2,10) = 0.349$, $p = 0.714$, $\eta^2 = 0.065$).

None of the other two-way interactions were significant: Site by Site Order, $F(2,22) = 2.729$, $p = 0.087$, $\eta^2 = 0.199$, Site by Stress Level, $F(2,22) = 0.30$, $p = 0.971$, $\eta^2 = 0.00$, Frequency Band by Order, $F(2.28,25.02) = 0.253$, $p = 0.805$, $\eta^2 = 0.023$, and Frequency Band by Stress Level, $F(2.28,25.02) = 1.309$, $p = 0.291$, $\eta^2 = 0.106$. The three way interaction between Site, Frequency Band and Order was not significant, $F(8,88) = 1.652$, $p = 0.122$, $\eta^2 = 0.131$, and neither was the interaction between Site, Frequency Band and Stress Level, $F(8,88) = 0.533$, $p = 0.829$, $\eta^2 = 0.046$.

Self-Reported Mood States

For the positive subscale of the PANAS, we found a significant main effect of Site, $F(2,58) = 3.698$, $p = 0.031$, $\eta^2 = 0.113$, demonstrating the strongest positive feelings were reported in the wetland setting ($M = 32.86$, $SD = 11.55$), followed by the control ($M = 30.29$, $SD = 10.03$), and then the urban ($M = 28.18$, $SD = 10.92$). There was no significant main effect of either Site Order, $F(1,29) = 0.186$, $p = 0.669$, $\eta^2 = 0.006$, or Stress Level, $F(1,29) = 2.434$, $p = 0.130$, $\eta^2 = 0.077$. None of the interaction effects were significant, for Site and Site Order, $F(2,58) = 1.588$, $p = 0.213$, $\eta^2 = 0.052$; for Site and Stress Level, $F(2,58) = 0.083$, $p = 0.921$, $\eta^2 = 0.003$.

For the negative subscale of the PANAS, we found a significant main effect of Site, $F(2,58) = 8.671$, $p = 0.001$, $\eta^2 = 0.230$. There was no significant main effect of Site Order, $F(1,29) = 0.209$, $p = 0.651$, $\eta^2 = 0.007$, but the main effect of Stress Level was significant, $F(1,29) = 5.352$, $p = 0.028$, $\eta^2 = 0.156$. Because we also found an interaction effect between Site and Stress Level, $F(2,58) = 0.083$, $p = 0.921$, $\eta^2 = 0.003$, we conducted a simple effects analysis, which demonstrated that for the subgroup classified as 'self-reported low stress,' PANAS negative scores did not differ between sites, $F(2,28) = 1.188$, $p = 0.320$, $\eta^2 = 0.078$, but those classified as more stressed reported significant differences, $F(2,28) = 8.585$, $p = 0.001$, $\eta^2 = 0.380$. Pairwise comparisons demonstrated significantly fewer negative feelings in the wetland setting compared with both the control ($p = 0.006$) and the urban setting ($p = 0.002$; both corrected for multiple comparisons) (**Figure 5**).

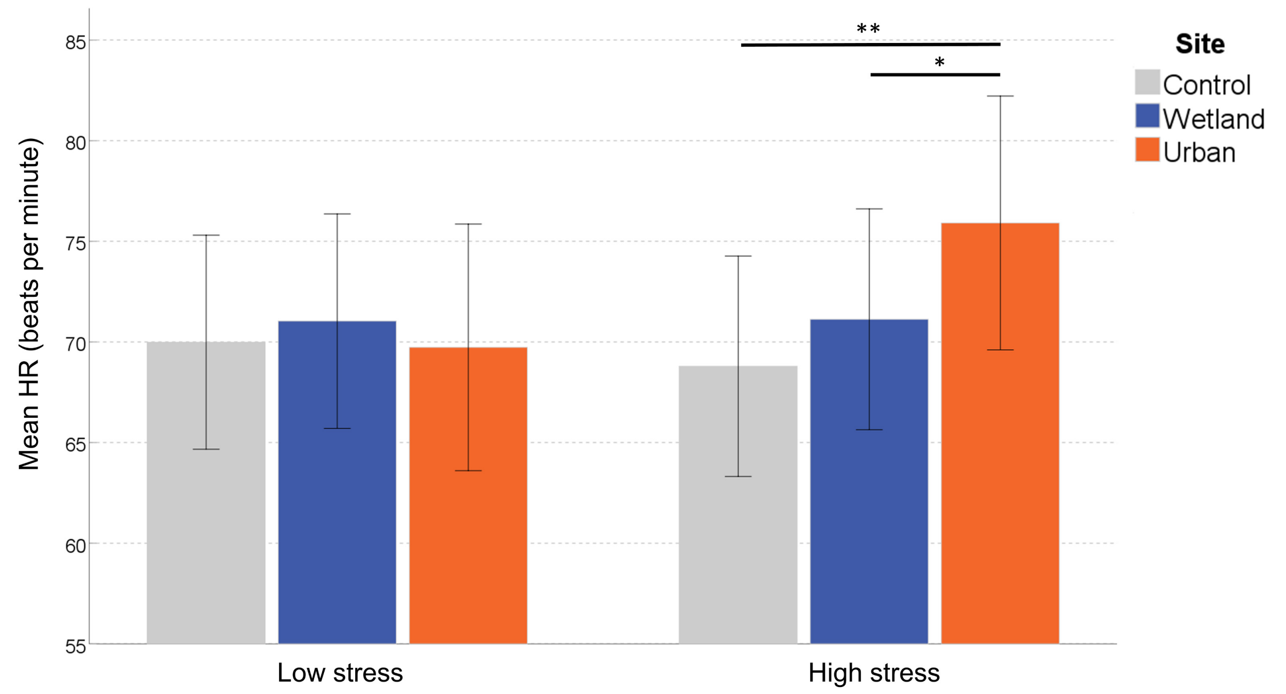

FIGURE 3 | Mean heart rate (HR) at each site. Error bars indicate 95% confidence intervals. Statistical significance is indicated by $*p < 0.05$ level, and $**p < 0.01$, corrected for multiple comparisons (Sidak).

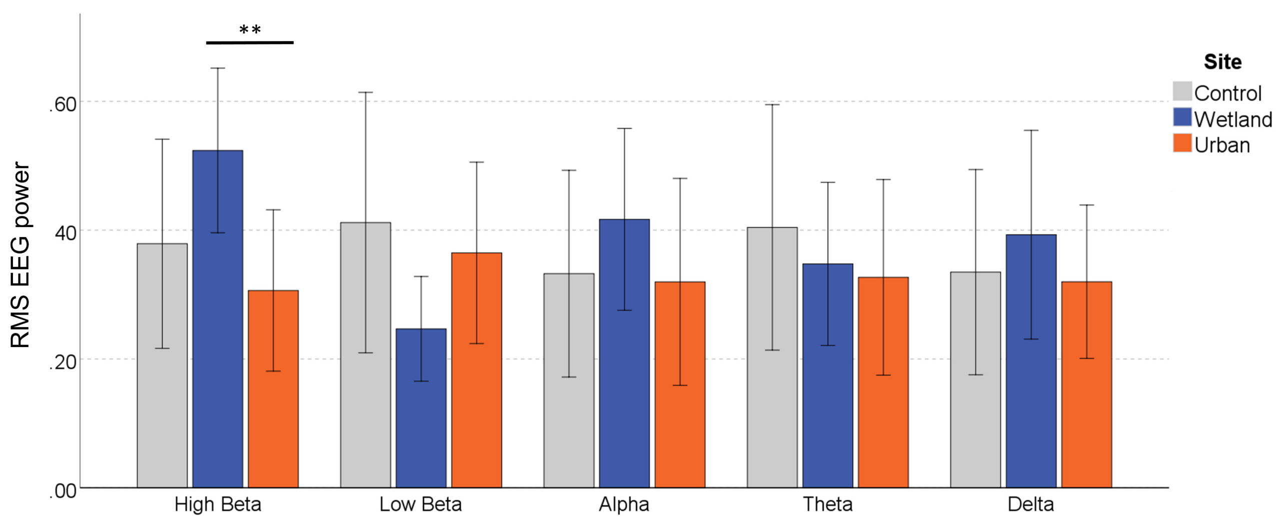

FIGURE 4 | EEG response in the different frequency bands during exposure to the wetland, urban and control sites. Error bars indicate 95% confidence intervals. Statistical significance is indicated by $*p < 0.05$ level, and $**p < 0.01$, corrected for multiple comparisons (Sidak).

DISCUSSION

Mental health is negatively associated with urban living (Pedersen and Mortensen, 2001; Van Os et al., 2004; Peen et al., 2010; Lederbogen et al., 2011) and positively associated with residential proximity to green and blue urban space (White et al., 2013; Alcock et al., 2014; Gascon et al., 2015). There is a growing interest across a broad set of disciplines – from public health to conservation biology – into how natural features might mitigate the impact of stress induced by urban environments (Thompson et al., 2014). Advances in wearable technologies now allows those managing blue and green spaces to monitor people's responses in real time and *in situ*. Here, we examine acute physiological and psychological stress responses during short-term exposure to a typical urban setting and an urban wetland in London, providing insight into the feasibility of using low-cost wearable

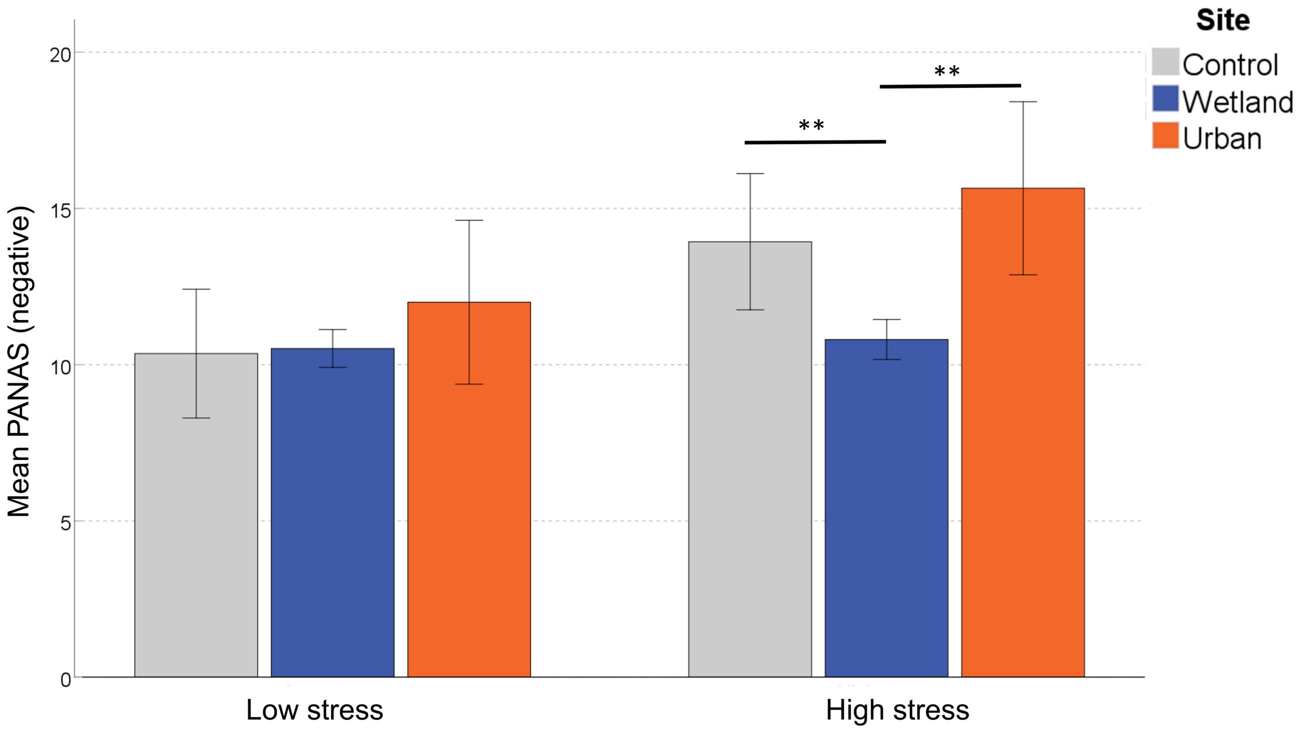

FIGURE 5 | Differences in self-reported negative mood following exposure to the three sites. Error bars indicate 95% confidence intervals. Statistical significance is indicated by *$p < 0.05$ level, and **$p < 0.01$, corrected for multiple comparisons (Sidak).

technology the monitor the HWB co-benefits of urban blue-green space.

Of the various physiological measures we acquired, only the HR response was found to be significantly different between exposure conditions. While acute cardiovascular responses to nature have been noted in earlier studies (e.g., Lanki et al., 2017), novel in our study was the finding that this effect was contingent upon participants' pre-exposure stress levels. Participants with higher than average levels of stress in the week prior to the experiment experienced an increase in HR in the urban, but not the wetland setting, relative to the baseline acquired indoors. As increased HR is an indicator of general physiological arousal, exposure to urban environments appears to cause a stress response, while wetland setting has a mitigating effect. In contrast to previous studies in which decreased HR was observed during exposure to green spaces relative to a control (e.g., Song et al., 2013; South et al., 2015; Grazuleviciene et al., 2015; Lanki et al., 2017), our findings suggest that acute exposure to blue–green spaces may induce a subtle and short-term moderation of cardiovascular stress reactivity. With the current experimental design we can only correlate this finding with the blue–green environment exposure, limiting the alignment of our observations with existing theories in the field e.g., the physiological and emotional stress moderation posited by Stress Recovery Theory (Ulrich, 1983). Further research is required in order to identify the mechanisms linking specific facets of the wetland environments to this observed moderation. Only with such advances can we begin to understand how the negative impacts of stressors associated with urban life may be mitigated through the expansion of BGI.

In addition to the physiological metrics, we also asked participants to report changes in mood states using a validated self-report instrument. Again, effects on mood state varied depending on participants' pre-exposure stress levels. Those with self-reported elevated stress levels in the week prior also reported a reduction in negative feelings after 10 min in the wetland compared with both the urban and control settings. This suggest at least a temporary improvement in subjectively experienced mood for those experiencing high stress in everyday life. In a similar vein, Roe and Aspinall (2011b) found more beneficial outcomes for adults in poor mental health during a rural walk. Korpela et al. (2008) and Ottosson and Grahn (2008) suggested that nature may have stronger restorative powers for people experiencing greater emotional stress. The evidence thus suggests that exposure to blue-green spaces can improve negative mood states. Interestingly, irrespective of whether participants were stressed prior to the experiment, a universal enhancement of positive mood states was observed following exposure to the wetland site, with people reporting feeling 'attentive,' 'inspired,' 'strong' and 'enthusiastic.' This finding confirms the positive association between blue-green space provision and hedonic wellbeing or life satisfaction (for a review, see: Houlden et al., 2017). Our findings therefore suggest that, in terms of subjective experience, exposure to urban blue space may have a dual effect of reducing stress and promoting more positive mood states, at least temporarily.

Based on the evidence that the wetland setting may induce both psychological and physical restoration, at least in those susceptible to stress, we had also expected to find a site-dependent moderation of brain activity. In particular, a state of relaxation or mediation would be associated with an increase in power across the alpha and theta frequency bands. However, only the high beta frequency band increased during wetland exposure, consistent with a state of enhanced attention. Under more controlled conditions (where participants passively viewed a series of videos), Olszewska-Guizzo et al. (2018) found increased power in the beta frequency band, located in temporal brain during the observation of 'contemplative' spaces relative to 'non-contemplative' outdoor spaces. They interpreted this pattern of brain activity as indicating more holistic perceptual processing and/or attention driven toward salient stimuli, associated with fascination. Increased beta-power could therefore be consistent with a restoration effect driven by involuntary attention shifts. There are good reasons, however, to be cautious when interpreting the EEG results. Few studies have attempted EEG measures *in situ* and across different environmental gradients, and results have been inconsistent. Previous studies using the Emotiv® EEG technology applied proprietary algorithms that automatically process and translate the EEG signals into mental state indicators. Aspinall et al. (2015) found lower 'frustration,' 'engagement' and 'arousal,' and higher 'meditation' when young participants walked into green space, and higher 'engagement' when moving out of it. Neale et al. (2017) reported that urban green space enhanced older participants' 'engagement,' whereas typical urban spaces promoted EEG activity associated with 'excitement.' There is – to our knowledge – no published research that reliably links these 'mental state' indicators with specific neural activity. The unconfirmed validity of this EEG analysis method led us instead to process the raw signals to derive the frequency band data within the EEG signal. Despite our attempts to improve electrode conductance (e.g., using glycerol/saline solution as recommended for longer measurement periods), our EEG observations are consistent with significant signal deterioration. The outdoor setting and an individual's movements whilst walking increased the likelihood of electrode displacement and signal interference. These effects cannot be resolved through *post hoc* statistical artifact correction. Significant loss of signal quality restricted the quantity of data available for processing. In addition, the low spatial resolution of the 14-channel Emotiv® system precludes analysis of signal origins, further complicating the interpretation of the data (but see Chen et al., 2015 for an example of a basic connectivity analysis demonstrating increased synchronicity in EEG waves during exposure to a natural environment). We report on averaged values across the full electrode network, and this broad-stroke approach, further compromised by the noisy signal due to acquisition problems, may have failed to capture the more subtle variations in brain function. Perhaps unsurprisingly, the user-friendliness and intuitive appeal of easy-to-use, low-cost mobile EEG systems is traded off against data quality. Research-grade systems are undoubtedly superior, but they require substantial training and may not be suitable for most mobile applications and limited budgets, and with some modifications acceptable accuracy can be achieved with low-cost systems (e.g., see Mavros et al., 2016). More research is required to establish validated protocols, optimize the electrode setup, and/or develop a range of bespoke modifications to increase signal quality and overall stability for mobile experiments.

We experienced similar technical difficulties with the acquisition and processing of some of the other psychophysiological metrics, which may have produced the negative findings on the HRV measures and indicators of EDA. Despite promising results in laboratory settings using images and 3-D simulations (e.g., Gladwell et al., 2012; Annerstedt et al., 2013; Brown et al., 2013), studies that have examined the effect of green space exposure on HRV (no studies have specifically examined blue spaces) report mixed findings (Kondo et al., 2018b). We hypothesize that this is due, at least in part, to the heterogeneity in how HRV is quantified. When derived using PPG, rather than ECG, measurements, HRV analysis involves several sequential calculations and each may apply different techniques (Michael et al., 2017). Despite the practical advantages, PPG devices may not (yet) provide useable HRV data suitable for monitoring and evaluating HWB benefits. We concur with Gidlow et al. (2016) who suggest that the level of noise in HRV recordings obtained under field conditions hampers our ability to discern meaningful and/or statistically significant differences in HRV response to changes in environmental exposure.

Contrary to our expectations, we also found no difference in EDA between the exposure conditions, despite the fact that skin conductance is less susceptible to the confounding effect of concurrent physical activity, and more closely linked to psychological arousal or stress. Evidence from other studies suggests that low-cost mobile sensors can provide data on par with research-grade systems (Torniainen et al., 2015; Zangróniz et al., 2017). One exploratory study found correlations between EDA activity and urban design features, demonstrating in particular that traversing green spaces was associated with reduced stress responses (Fathullah and Willis, 2018). However, as with the HRV data, a likely explanation for the negative finding is the low EDA signal quality. Environmental factors such as temperature and humidity, and a participant's sweat production, are known to affect EDA, which can lead to inconsistent results, especially in field experiments and when analyzing short epochs (e.g., Doberenz et al., 2011). Our analysis and interpretation of the EDA data may also have been hampered by an inadequate period for the baseline measure. The 10 min baseline obtained in the control room did not provide sufficient insight into the tonic aspect of the signal, which varies between individuals and across normal diurnal patterns (e.g., Hot et al., 1999). In future studies, an observational approach in which participants wear the Empatica E4 monitor for a pre-experiment period of 24 h (or longer) combined with GPS location services could provide rich data that would allow direct comparisons in responses to various urban design features in an ecologically valid manner.

In addition to the technological challenges outlined earlier, we recognize a number of limitations associated with our experimental design. Time constraints limited the environmental exposure to a single wetland site, comprising both blue and green elements, and an urban site. The environments vary on a great number of variables, across a range of perceptual domains. This precludes judgments on the specificity of the observed effects. It remains unclear whether exposure to other types of blue and/or green spaces could deliver similar benefits. The absence of a green environment control (e.g., a municipal parkland) means we are unable to determine the impact of urban wetland habitat as opposed to any other non-built environment. As such our conclusions are drawn using more generic terms around 'blue–green space' as opposed to 'blue space.' Future studies should incorporate a greater range of environmental stimuli to identify specific elements producing strong effects, what the role of biodiversity is (Dean et al., 2011; Dallimer et al., 2012; Clark et al., 2014) and whether perceived or 'objective' quality and type of habitat matters (Wheeler et al., 2015).

Due to the age range and anticipated variation in physical condition within the participant sample, any psychophysiological measure would be subject to large inter-individual variation, which introduces measurement noise and impacts the detection of statistically significant differences in a relatively small sample. While our sample size compares favorably with similar quasi-experimental studies (Kondo et al., 2018b), we caution against extrapolation, and emphasize the need to re-examine these effects at different sites and with larger, and possibly more homogeneous samples. Inter-individual variation may be mitigated by obtaining more robust baselines against which exposure responses can be compared, e.g., through unobtrusive 24-h measurements (Kondo et al., 2018b). Such recordings are certainly possible with the PPG wristband, but for the EEG measure, this remains impractical for a wide range of applications as the individual needs to carry the acquisition device (e.g., laptop) in addition to wearing the headset. Furthermore, 70% percent of participants we queried (21/30) reported discomfort from prolonged wearing of the headset, with initial signs of irritation or physical discomfort occurring during the experimental session. This may have caused both technical problems (e.g., more movement artifacts) and influenced the mental state of participants, confounding the EEG results. Our experimental setup may have therefore tested the limits of the current technology.

Our categorization of participants into self-reported stressed and non-stressed (defined against normative UK data; Henry and Crawford, 2005) has limitations because it does not fully encompass the complexity of the environment-stress dynamic at an individual level. Differing environments, personal experience and individual capabilities are likely to interact to produce differential psychological responses. For example, we have assumed that the 'self-reported high stress' subset did so based on a depletion in personal resource and that the 'self-reported low stress' subset did so through a perceived lack of depletion. This fails to recognize the role of 'instoration' (the accruing of adaptive personal resources (e.g., self-esteem) beyond the restoration of a deficit (Hartig et al., 1996). We also do not know the role the environment plays in instoration. For example those reporting as 'low stress' might have experienced improved mental health by residing in areas with good green or green-blue space provision (White et al., 2013; Alcock et al., 2014). As such there is a need for more instorative studies on the role the environment plays in building health resilience (Roe, 2008; Roe and Aspinall, 2011a). Such studies would help tackle important evidence gaps on the mechanisms around how differing natural and built environments (or facets of those environments) contribute to building or depleting individual resources. For example what dose or exposure (Barton and Pretty, 2010; Cox et al., 2017; White et al., 2019) or level of biodiversity (Aerts et al., 2018) might be required to build resilience, and for whom? Such studies might also advance findings on the beneficial effects of nature that manifest even when participants are not exposed to any psychological depletion (Beute and De Kort, 2014). Such advances have important policy and advocacy implications for those agitating for greater BGI provision in urban environments for health and broader ecosystem services that benefit people.

As highlighted by Roe and Aspinall (2011b), the quasi-experimental design employed in field experiments presents a number of limitations. First, it is difficult to control for the many confounding variables that impact on participant comfort and experience in outdoor environments. We managed this to some extent with the timing of the experiment. We had favorable weather and a capacity to stipulate testing days without rain, wind or cold temperatures. Cloud cover was the most variable weather feature, and we do anticipate that differences in the level of sunshine are likely to stimulate variations in both physiological and psychological response, as well as producing additional risk of sweat-related artifacts on the EEG and EDA measures. Variation between morning, lunch and afternoon sessions potentially introduced diurnal physiological differences. In the urban environment, when the general public unexpectedly interrupted testing, we retested participants, however, we were unable to control the number of passers-by in both urban and wetland and how this may have affected participants. Another possible confounding variable is prior experience and knowledge of the site and surrounds.

Our experimental manipulation mimics the incidental nature of exposure to BGI in urbanites (Keniger et al., 2013; Beery et al., 2017). The results mainly illustrate the psychological (mood-based) effects of one-off blue-green space exposures in urban settings, and highlight potential concomitant physiological effects that require more detailed investigation. An interesting further research direction concerns the issue of whether and how the benefits of incidental exposure accumulate over time and across a life course. It also remains to be demonstrated whether there are any particular environmental characteristics or design features in managed settings that produced the enhanced psychological benefits. This level of detail was beyond the scope of the current study, but a deeper understanding will be required to adequately inform and optimize the implementation of BGI for mental and physical health salutogenesis in urban areas.

CONCLUSION

In this experiment, we aimed to test the salutogenic potential of an urban wetland, using commercially available, low cost wearable technologies. Whilst only the most robust physiological measure showed a differential response to the wetland environment compared to the urban environment, our results are consistent with the hypothesis that exposure to blue–green space promotes stress recovery. People that are already experiencing a high level of stress may be at greater risk of developing health problems due to an increased physiological stress response in busy urban environments. At the same time, individuals experiencing high stress appear to derive some relief from negative mood states during green–blue space exposure, which also enhances positive feelings in most people. Further research is required to examine the degree to which the provision of BGI in urban environments has preventative and curative benefits, and to validate whether incidental exposure is sufficient to achieve meaningful effects over long-term timeframes and across a larger number of response variables.

Finally, our experience indicates that wearable monitoring devices have an intuitive appeal with various stakeholders, including the academic community, conservation organizations, the public, and results may be persuasive with policy makers. We urge vigilance amongst those considering implementing this technology, to recognize the risk it poses in becoming a fad across the environment sector, as has occurred with other potential solutions in the past (Redford et al., 2013). The drive toward an evidence-based approached risks being hijacked by such a fad if the challenges of successfully navigating research-implementation 'spaces' (Toomey et al., 2017) are subsumed by the latest technological wizardry. We must therefore remain vigilant as we work toward expanding the evidence base on public health benefits as a robust argument for the conservation of blue and green space in our urban environment.

DATA AVAILABILITY

The dataset generated for this study can be found on a dedicated page within the Open Science Framework domain, maintained by the Center for Open Science (COS) (https://osf.io/kfxsr/).

ETHICS STATEMENT

This research was conducted in accordance with the RCUK Policy and Guidelines on Governance of Good Research Conduct (updated in 2017) and the guidelines set out by Imperial College London (https://www.imperial.ac.uk/research-and-innovation/about-imperialresearch/research-integrity/ethics/human/). All data was stored in accordance with the UK Data Protection Act of 1988 (which was in force when the project commenced) and the EU General Data Protection Regulation which came into force in 2018. An internal review process within the Department of Life Sciences was used to investigate the ethical dimensions of the proposed research. Further elevation to a full review by the Imperial College Research Ethics Committee (ICREC) was not required on the basis of this initial assessment. The above process followed standard procedures for the assessment of low-risk, non-medical human research studies, as approved by the Head of Department of Life Sciences and the Head of Regulatory Compliance (within the Joint Research Compliance Office) at Imperial College London.

AUTHOR CONTRIBUTIONS

JR, AV, RC, and AK conceived the research and secured funding for the project. JR and AV developed the study design, oversaw the data collection and analysis, and drafted the initial version of the manuscript. JR, AV, and ES analyzed and interpreted the data. VH contributed to participant recruitment and data collection. CN contributed to the development of the study design and data analysis. All authors contributed to the writing and editing of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01840/full#supplementary-material

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Camera Stabilization in 360° Videos and Its Impact on Cyber Sickness, Environmental Perceptions, and Psychophysiological Responses to a Simulated Nature Walk: A Single-Blinded Randomized Trial

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Immersive virtual environments (IVEs) technology has emerged as a valuable tool to environmental psychology research in general, and specifically to studies of human–nature interactions. However, virtual reality is known to induce cyber sickness, which limits its application and highlights the need for scientific strategies to optimize virtual experiences. In this study, we assessed the impact of improved camera stability on cyber sickness, presence, and psychophysiological responses to a simulated nature walk. In a single-blinded trial, 50 participants were assigned to watch, using a head-mounted display, one of two 10-min 360° videos showing a first-person nature walk: one video contained small-magnitude scene oscillations associated with cameraman locomotion, while in the other video, the oscillations were drastically reduced thanks to an electric stabilizer and a dolly. Measurements of cyber sickness (in terms of both occurrence and severity of symptoms), perceptions of the IVE (presence and perceived environmental restorativeness), and indicators of psychophysiological responses [affect, enjoyment, and heart rate (HR)] were collected before and/or after the exposure. Compared to the low-stability (LS) condition, in the high-stability (HS) condition, participants reported lower severity of cyber sickness symptoms. The delta values for pre–post changes in affect for the LS video revealed a deterioration of participants' affect profile with a significant increase in ratings of negative affect and fatigue, and decrease in ratings of positive affect. In contrast, there were no pre–post changes in affect for the HS video. No differences were found between the HS and LS conditions with respect to presence, perceived environmental restorativeness, enjoyment, and HR. Cyber sickness was significantly correlated with all components of affect and enjoyment, but not with presence, perceived environmental restorativeness, or HR. These findings demonstrate that improved camera stability in 360° videos is crucial to reduce cyber sickness symptoms and negative affective responses in IVE users. The lack of associations between improved stability and presence, perceived environmental restorativeness, and HR suggests that other aspects of IVE technology must be taken into account in order to improve virtual experiences of nature.

Keywords: green exercise, virtual reality, restorative environments, environmental perception, immersive virtual environments

INTRODUCTION

Nature is believed to have intrinsic qualities that promote health and well-being (Bowler et al., 2010; Bosch and Bird, 2018), which has led to increased interest in nature exposure as a research area. In the past two decades, interest and concerns have been raised regarding the possibility of using *virtual nature* to supplement exposure to real nature. Virtual nature might be a tool to increase the exposure to restorative nature experiences in an increasingly urbanized population and might even contribute to the reconnection of people to real nature, as studies show that acute bouts of green exercise (i.e., any physical activity performed while being exposed to nature) can increase people's feelings of nature connectedness (Mayer et al., 2009) and future intention to exercise and/or visit natural environments (Hug et al., 2008; Calogiuri and Chroni, 2014; Calogiuri et al., 2015). The effectiveness of this technology as an instrument in palliative care has been documented (Chirico et al., 2016; White et al., 2018). This technology could also address some of the major methodological issues inherent to environmental research (Smith, 2015), particularly in studies of natural environments (Lahart et al., 2019), as research related to outdoor environments does not allow strict control of confounding factors such as weather conditions, temperature, ambient noises, etc. To date, however, it remains unclear to what extent virtual nature can provide benefits equivalent to those provided by experiences in real nature, while on the other hand, concerns have been raised regarding the possible undesired effect of further distancing people from real nature (Levi and Kocher, 1999). Moreover, in spite of the fact that virtual reality has become a phenomenon of mass consumption, a series of side effects that can undermine the quality of users' experience yet remain to be addressed. These side effects are also known to mask potential effects in studies of virtual environments, thus limiting the usefulness of virtual technology in environmental research.

The Effectiveness of Virtual Nature

The potential of and the interest in virtual nature have been accelerated by the upcoming and continuous development of immersive virtual environments (IVEs) technology. IVEs are virtual environments that "surround an individual and create the perception that they are enclosed within and interacting with environments that provide a continuous stream of stimuli" (Smith, 2015). Head-mounted displays, devices with a motion sensor that allows a 360° vision of a virtual world while eliminating the visual contact with external reality, are central elements of IVE technology. These displays are considered more immersive than traditional displays and are believed to increase *presence*, i.e., the illusion of "being there" (Weech et al., 2019), which is considered a key element of the effectiveness of virtual environments (Steuer, 1992). The popularity of IVEs and head-mounted displays follows the introduction of affordable technology that not only provides the opportunity to immerse oneself in pre-set IVEs, but also allows the creation of new IVEs using special 360°cameras and freely available and customizable applications. *Static* IVEs (i.e., IVEs in which the perspective of the viewer is stationary, but still allow a 360° range of vision) have been shown to be able to replicate some of the positive psychological effects of exposure to real nature (Chirico and Gaggioli, 2019; Yu et al., 2018), such as helping people reduce stress (Liszio and Masuch, 2018) or experiences of pain (Chirico et al., 2016; White et al., 2018). The effectiveness of virtual environments has further been confirmed in studies of urban environments, in which virtual images and soundscapes are perceived as comparable to the real environment (Maffei et al., 2016; Hong et al., 2019).

While the literature provides increasingly strong support for the effectiveness of static natural IVEs, more challenges are encountered in relation to *dynamic* IVEs (i.e., IVEs in which the perspective of the viewer moves while allowing a 360° range of vision, for example, a simulated walk in a natural environment). Previous studies have found some psychological benefits of exposure to dynamic IVEs administered either in sedentary conditions (Valtchanov et al., 2010) or in combination with physical movement (Plante et al., 2003, 2006). The head-mounted displays used in these studies, however, only allowed a 60° to 65° range of vision, thus not fully engaging the viewers' peripheral vision. To the best of our knowledge, only one study has used *dynamic* 360° IVEs to compare a simulated nature walk (both in combination and not in combination with actual physical movement) to an actual outdoor walk in the same environment (Calogiuri et al., 2018). The results from this study suggest that the technology might have the potential to elicit psychological responses similar to those experienced in real nature, as in fact the participants assigned equivalent levels of perceived environmental restorativeness in the IVE as in the real environment and spontaneously walked at the same pace in both conditions. However, the users reported a significant deterioration of their psychological state after exposure to the IVE, with a decrease in positive emotions (tranquility and positive affect) and an increase in negative emotions (fatigue and negative affect). Such dramatic psychological responses appeared to be primarily associated with the experience of a phenomenon known as *cyber sickness*.

The Impact of Cyber Sickness on the Effectiveness of Virtual Nature

Cyber sickness mimics the symptoms of motion sickness, inducing feelings of dizziness, nausea, and general discomfort (Smith, 2015), and can be viewed as a specific type of visually induced motion sickness (Kennedy et al., 2010). There has been an increase in reported cases of cyber sickness in recent years, which may relate to the fact that more technologically advanced displays, such as head-mounted displays, generally induce higher levels of cyber sickness (LaViola, 2000; Sharples et al., 2008). There are two prevailing theories regarding the cause of cyber sickness. The *sensory conflict theory* postulates that cyber sickness is caused by sensory conflict between visual, vestibular, and proprioceptive inputs (Reason and Brand, 1975). Another explanation to how cyber sickness may originate is provided by the *postural instability theory*, which states that long periods without postural control will cause cyber sickness (LaViola, 2000). The negative effects caused by cyber sickness is a concern in studies of virtual environments as it is likely to act as a competing factor to the potential benefits of exposure to virtual nature. For example, recent research suggests that cyber sickness is inversely related to presence and that reducing cyber sickness might improve presence (Weech et al., 2019). Cyber sickness may also compete with the environmental perceptions. According to Rachel and Stephen Kaplan's Attention-Restoration Theory, environments characterized by qualities of fascination, compatibility, extent, and feeling of being away have the potential to elicit cognitive restoration and positive affective responses (Kaplan, 1989, 1995). However, Calogiuri et al. (2018) compared affective responses after exposure to real and virtual natural environments and found that the real environment induced a more positive affective response compared to the virtual environment, despite the fact that the participants perceived the virtual environment as having restorative properties equivalent to those perceived in the real environment. Calogiuri et al. (2018) further demonstrated medium to high correlations between cyber sickness and participants' affective responses, which suggest that cyber sickness disrupted any potential positive effects related to the restorative value of the virtual environment. The discomfort caused by cyber sickness and its potential impact on affect and presence limit the application of VR in health promotion and research purposes, and highlight the need for scientific strategies to optimize virtual experiences. Interestingly, recent advances in handheld stabilizing devices specifically designed for 360° cameras provide a potential strategy. These stabilizing devices reduce camera oscillations, which might reduce levels of cyber sickness.

The Impact of Scene Oscillations on Cyber Sickness

It has been hypothesized that the presence of scene oscillations might play a central role in the generation of cyber sickness during exposure to dynamic IVEs. Oscillations, which include movements of the scene displayed in the head-mounted displays on the horizontal and/or vertical axis (also known as "pitch and yaw"), are an issue in the development of dynamic IVEs, especially those developed using 360° cameras. Such oscillations may be generated as a consequence of poor stabilization of the camera (e.g., general vibrations) as well as vertical movements associated with the locomotion of the camera operator. Previous provocation studies, i.e., participants were exposed to a stimulus that was expected to provoke a negative response, have investigated the effect of oscillations using head-mounted displays (Lo and So, 2001; Bonato et al., 2009). In these studies, they intentionally created computer-generated IVEs with severe levels of oscillations and found that an increase in oscillations increases levels of cyber sickness (Lo and So, 2001; Bonato et al., 2009). It is not clear how the presence of oscillations leads to increased levels of cyber sickness. However, it has been suggested that when the viewer experiences the scene moving in one direction, it causes a feeling of self-motion (i.e., vection) in the opposite direction (Lo and So, 2001). This sense of self-motion perceived by the visual sensory system might cause sensory conflict with input from the vestibular and proprioceptive systems, as these sensory systems would not perceive any motion in this situation, thus linking the sickness-inducing effect of oscillations to the sensory conflict theory. Although this is just a theory and researchers debate whether or not vection actually is related to cyber sickness (Keshavarz et al., 2015), the studies of Lo and So (2001), and Bonato (2009) have established that high levels of artificially generated oscillations have a severe impact on cyber sickness. However, it is still unknown whether this applies to more practical situations and, in particular, to what extent minimizing oscillations can reduce levels of cyber sickness in 360° videos that are not intentionally designed to provoke a negative response.

The Present Study

The purpose of the present study was to assess the extent to which improved camera stability, in dynamic 360° videos simulating a nature walk, could reduce cyber sickness and improve participants' sense of presence and psychophysiological responses.

> Our primary hypothesis was stated as follows:
> A 360° video simulating a nature walk with a high level of camera stability will be associated with less severe symptoms of cyber sickness compared to a less stable video.
>
> Our secondary hypotheses were stated as follows:
> 1.1. If a highly stable 360° video simulating a nature walk induces less cyber sickness, it will also be associated with higher levels of presence compared to a less stable video.
> 1.2. If a highly stable 360° video simulating a nature walk induces less cyber sickness, it will also be associated with a more positive psychophysiological response compared to a less stable video.

In addition, in relation to each hypothesis, we performed an exploratory correlation analysis investigating possible associations between the variables in order to evaluate possible pathways that can help explain the complex relation linking cyber sickness, environmental perceptions, and psychophysiological responses.

MATERIALS AND METHODS

This paper is structured in line with the CONSORT guidelines (Schulz et al., 2010).

Participants

Estimation of required sample size was based on total score on the simulator sickness questionnaire (SSQ) from a preliminary pilot study done in our laboratory. The smallest meaningful between-group difference in total SSQ score was set to 20, with a pooled standard deviation of 30. α-level and desired power was set to 0.05 and 80%, respectively. Based on this calculation, an approximate sample size of 50 was deemed appropriate. Participants were recruited by the first author among students and non-scientific employees at the Inland Norway University of Applied Sciences (Elverum), but also a few participants outside the University during the months of June and August–October. Inclusion criteria were as follows: being $\geq$18 years old, having normal or corrected-to-normal vision, having limited experience with VR (less than monthly use), and not having previous diagnosis of balance impairments. The final sample comprised 22 males and 28 females. Participants' background characteristics are presented in **Table 1**. All participants signed a written informed consent prior to the experiment. The study was approved by the Norwegian Center for research data (reference number: 60451) and conducted according to the declaration of Helsinki.

IVE Technology and Experimental Conditions

The IVEs used for the experiment consisted of two 10-min-long 360° videos showing a first-person walk along a path in a natural environment. The playback was made using Samsung S7, with Android 7.0, mounted on a Samsung Gear head-mounted display (Samsung Gear VR SM-R323). The environment contained a fairly straight paved trial in natural surroundings alongside a river in Elverum. In addition to natural elements such as trees, grass, and water, the environment also included some buildings and a football field. An actual walk of the same duration along the same path has previously been reported to improve participant's affect state, with significant reductions in fatigue and negative affect, but no changes in tranquility and positive affect (Calogiuri et al., 2018).

TABLE 1 | Baseline characteristics of the participants (n = 50).

	LS (n = 25)	HS (n = 25)
Male (n)	11	11
Female (n)	14	14
Variables	**M (SD)**	**M (SD)**
Age (years)	30.6 (11.6)	30.0 (11.3)
BMI (kg/m^2)	25.8 (3.5)	24.6 (3.1)
Weekly physical activity (METs)	54.8 (22.3)	59.6 (26.4)

LS = low stability video. HS = high stability video. BMI = body mass index.

The two videos showed the same nature walk and differed only in the extent to which they contained frequent scene oscillations of small magnitude. Both IVEs were recorded in the same location using the same 360° video camera (Samsung gear 360 smc200, 3840 × 1920 resolution at 30 frames per second), in pleasant weather conditions. Measures were taken to ensure that all elements except camera oscillations would be as similar as possible. This includes recording the scene segments at the same time of year with similar levels of "greenness," matching the lighting postproduction based on the subjective evaluation of the authors, matching start and end position of the videos, etc. The low-stability (LS) video was created using segments from a video used in a previous experiment (Calogiuri et al., 2018). To develop that video, a 360° camera was mounted on a modified Yelangu s60t mechanical handheld stabilizer and the video recorded was run through two software stabilizing programs as described in Calogiuri et al. (2018). This procedure was developed to minimize camera oscillations, but due to the oscillations associated with the camera operator locomotion as well as the mechanical nature of the stabilizer, oscillations of small magnitude still occurred along both the vertical and horizontal axis. In contrast, the high-stability (HS) video was recorded by mounting the 360° camera on an electronic gimbal handheld stabilizer (Feiyu Tech G360), which provided a high degree of stability, especially in the horizontal axis (pitch). The camera operator was also pushed along the path on a dolly to further minimize oscillations in the vertical axis (yaw). This procedure effectively eliminated pitch oscillations though, in order to align the camera positioning with the path, yaw oscillations of small magnitude still occurred sporadically (six times during the entire duration of the video). The two videos were similar in all aspects, but differed in both frequency and magnitude of oscillations.

Instruments

Cyber Sickness

The occurrence of cyber sickness was measured with a dichotomous question: "are you cyber sick," followed by a brief verbal explanation of the term, to which the participant responded either "yes" or "no" (Merhi et al., 2007; Munafo et al., 2017). The SSQ was used to measure the severity of the symptoms related to cyber sickness (Kennedy et al., 1993). As the name implies, the SSQ was designed to measure simulator sickness, but the questionnaire has seen widespread use in studies of cyber sickness as well (e.g., Draper et al., 2001; Merhi et al., 2007; Munafo et al., 2017). Participants were asked to rank, on a four-point Likert scale, the severity of 16 different symptoms such as "Headache" and "Increased salivation." Scoring and analysis of the SSQ data were performed according to the recommendations of Kennedy et al. (1993). The scale showed adequate internal consistency for the total score (α = 0.94).

Presence and Environmental Perceptions

To assess participants' sense of presence in the IVEs, we used a scale based on the approach of Nichols et al. (2000), which includes eight items related to presence in virtual environments. The items were formulated as statements as shown in **Table 2**, and participants were asked to rate their level of agreement

TABLE 2 | Items used to assess presence.

Short name	Item
Being there	In the computer-generated world, I had the sense of "being there"
Realism	I thought of the virtual environment as equal to the real environment
Sense of reality	The virtual world became more real or present to me compared to the real world. NB: by "real world," we mean the room where you were undergoing the test
Awareness	During the "virtual walk," I often thought of the other person(s) in the room with me
Other persons	It would have been more enjoyable to engage with the "virtual world" with no one else in the room
External noises	While I was doing the "virtual walk," I paid much attention to other noises around me in the room
Flatness	The virtual world appeared flat and missing in depth
Movements lag	The lag, delay or difference between my movements and the movements in the "virtual walk" were disturbing

to each statement on an 11-point Likert scale. Alongside the measure of presence, the extent to which the participants perceived the IVEs as having a potential for environmental restorativeness was assessed by administering the perceived restorativeness scale (Hartig et al., 2003). In the context of our study, this measure provided an indicator of the potential of the IVEs to elicit cognitive restoration. The scale consists of 16 items, rated on a 11-point Likert scale (0 = absolutely disagree, 10 = absolutely agree), which assess the subjective perception of four environmental qualities in line with Rachel and Stephen Kaplan's Attention-restoration theory (Kaplan, 1989, 1995): Being away, which refers to the extent to which the environment provides a feeling of "being away" from everyday demands and concerns (two items, e.g., "It was an escape experience"); Fascination, the environment's ability to capture the viewers' effortless attention (five items, e.g., "The setting has fascinating qualities"); Coherence, the extent to which the elements in an environment combines to a coherent whole (four items, e.g., "There is too much going on"); and Compatibility, which describes how well a place fits people's inclinations and interests (five items, e.g., "have a sense that I belong there"). The caption on top of the items explicitly stated "The following questions relate to the virtual environment." The scale showed adequate internal consistency ($\alpha = 0.74–0.86$).

Psychophysiological Responses

The participants' psychophysiological responses to the different IVEs were evaluated in relation to enjoyment, pre-to-post changes of affect, and heart rate (HR). Enjoyment was assessed after exposure to the IVE using a single-item inquiring: "on a scale from 1 to 10, how enjoyable was the activity you engaged in?" This measure has been used in studies investigating participants' affective responses to green exercise, showing high correlation with measurements of perceived environmental restorativeness (Calogiuri et al., 2015, 2018). Participants' affect was assessed before (Pre) and after (Post) exposure to the IVE using the Physical activity affect scale (Lox et al., 2000). The scale consists of 12 items (e.g., "energetic," "calm," "miserable," and "tired") that, in line with Russel's circumplex model (Russell, 1980), are grouped in four components: Positive affect (positive valence, high activation), Tranquility (positive valence, low activation), Negative affect (negative valence, high activation), and Fatigue (negative valence, low activation). The scale showed, in general, adequate internal consistency for the different subscales ($\alpha = 0.68–0.87$), though somewhat poor levels of internal consistency were found for Positive affect in the Pre assessment ($\alpha = 0.56$) and Negative affect in both assessments ($\alpha = 0.56–0.56$, in Pre and Post, respectively). Lastly, HR was recorded continuously over a 6-min period during exposure to the IVEs using a HR-monitor (Polar FT60M BLK WD) and extracted as beats per minute as a physiological indicator of stress (Allen et al., 2014; Duzmanska et al., 2018). It was decided to exclude the first and last couple of minutes of video exposure from the HR measurements to allow postural adaptation of HR in the beginning of the video, as the participants moved from a standing to a seated position, and due to concerns that the fact that the examiner reentered the experimental room at the end of the video would influence HR. Mean HR (HRmean), the mean of all individual measurements, and maximal HR (HRmax), the single highest value recorded, were automatically recorded by the HR monitor and used for further analyses.

Participants' Background Characteristics

This information was collected in order to establish a general indication of the health and fitness status of the participants, and included sex, age, body mass index (BMI), and physical activity habits. Sex and age were self-reported by the participants, while BMI was calculated [body weight (kg)/height $(m)^2$] based on assessments of height and body weight performed in the laboratory prior to participation in the experiment. The participant's physical activity levels were assessed using an adjusted version of the leisure time exercise questionnaire (Godin and Shephard, 1985), which was modified in the caption to include transportation physical activity (i.e., walking or biking to reach different destinations). This adjusted version of the leisure time exercise questionnaire was used in a previous study and was found to correlate with objective assessments of physical activity by accelerometer (Calogiuri et al., 2013).

Design and Procedure

The study was designed as a single-blinded experimental trial with two parallel groups. Participants were allocated to either one of the two experimental conditions with a 1:1 allocation ratio based on a predetermined sequence (i.e., the first participant was assigned to the LS IVE, the second to the HS IVE, the third to the LS IVE, and so on). This allocation procedure was chosen to ensure that an equal amount of experiments was carried out in each group in the same time period, as some participants were tested in June and some in August–October due to practical reasons. The allocation, which was determined by the first author, was stratified by sex to assure a balanced distribution of males and females in each group. This allocation was strictly based on the predetermined sequence, which was developed when the researchers were still unaware of the participants' order, and never modified to accommodate participants' preferences or characteristics. All participants were blinded to which condition they were allocated to and were unaware of the difference between the two IVEs. The experiment was performed in a controlled laboratory environment at Inland Norway University of Applied Sciences (Campus Elverum), with standardized temperature, ventilation, and lighting, and a high degree of sound insulation. The participants viewed the IVE while seated, and both videos lasted 10 min to approximate the exposure duration that give the largest effects on psychological outcomes according to the meta-analysis by Barton and Pretty (2010). No changes to methods were made after trial commencement.

The experimental procedures were performed as follows: (1) measurement of height and weight; (2) pre-exposure questionnaire, including physical activity affect scale and background information; (3) exposure to the IVEs, with continuous recording of HR from the third to the ninth minute of the IVE; and (4) post-exposure questionnaire, including SSQ, presence, perceived environmental restorativeness, physical activity affect scale, and enjoyment. In addition to the ones listed above, the study included additional measurements (i.e., a measure of future green exercise intention and assessments of postural stability during the first and last minute of video exposure), which are not presented in this paper.

Analyses

The data were preliminarily explored in order to examine the frequency distribution of the various variables as well as identify possible missing values and outliers. The assumption of normality was evaluated by a Shapiro–Wilk test, which revealed that none of the outcome variables were normally distributed. Hence, a Mann–Whitney *U* test was used to investigate possible differences between the two IVE conditions for the SSQ scores, the eight items of presence, the four components of perceived environmental restorativeness, the four components of affect (expressed as delta values: post-exposure - pre-exposure), enjoyment, and HR. Potential between condition differences for the dichotomous measure of cyber sickness were analyzed by a chi-square test. In order to establish possible pre-to-post changes in the four different components of affect, a Wilcoxon signed-rank test was also applied to each of the affect components (Positive affect, Tranquility, Negative affect, and Fatigue). Lastly, a Spearman's rank correlation coefficient (ρ) was used as an exploratory analysis to evaluate potential associations between cyber sickness, and presence, and all outcome variables. Because of the large number of between- and within-group comparisons, the level of significance was adjusted using the Benjamini–Hochberg procedure with a false discovery rate of 5%. Adjusted *p*-values are presented throughout the manuscript for between- and within-group comparisons. The correlation analysis was considered an exploratory analysis and, thus, the Benjamini–Hochberg procedure was not applied (Victor et al., 2010). All measurements were treated in accordance with standard procedures normally adopted for each instrument, and the overall statistical strategy was consistent with plans done prior to implementation of the study.

All outcome variables are presented as median (Mdn) and interquartile range (IQR). All statistical analyses were performed in IBM SPSS statistics 24 (IBM, New York, NY, United States). The significance level was set at $p < 0.05$.

RESULTS

The participants were generally considered active and healthy individuals with a mean (±standard deviation) age, height, weight, BMI, and modified leisure time exercise questionnaire score of 29.8 (±10.8) years, 173 (±10) cm, 76.1 (±14.9) kg, 25.2 (±3.3) kg/m^2, and 57.2 ± 24.3 units, respectively.

Three participants did not complete the full 10 min of video exposure due to high levels of cyber sickness. All three participants watched the LS video and discontinued after 3 min 56 s, 5 min 40 s, and 6 min 55 s. Data for all assessments were obtained for these participants and were included in the analysis (see flow diagram in **Figure 1**). Unfortunately, HR data were missing for two participants due to technical difficulties, and both of these participants were exposed to the HS condition.

Cyber Sickness

The dichotomous measure of cyber sickness revealed that 4 out of 25 participants (16%) in the HS condition and 12 out of 25 participants (46%) in the LS condition reported being sick. This effect was marginally not significantly different between the two conditions (χ^2 = 5.88, adjusted p = 0.055). As shown in **Figure 2**, the Mann–Whitney *U* test on the total scores from the SSQ showed that participants in the HS condition reported significantly less severe symptoms of cyber sickness compared to participants in the LS condition (LS: Mdn = 33.66, IQR = 14.96–99.11; HS: Mdn = 18.70, IQR = 1.87–35.53, U = 179.0, adjusted p = 0.039).

Spearman's rank correlation showed no significant correlations among SSQ scores and any of the components of presence or perceived environmental restorativeness. On the other hand, the analysis revealed medium to high correlations between SSQ scores and enjoyment and all components of affect (**Table 3**). No significant associations were found among the SSQ scores and HR.

Presence and Environmental Perceptions

As shown in **Figure 3**, the sense of presence in the IVEs was similar in the two experimental conditions, with no significant between-condition differences for any of the eight items of presence (adjusted p = 0.179–0.899). Similarly, no significant differences between the two experimental conditions were found for the components of perceived environmental restorativeness (adjusted p = 0.589–0.938, **Figure 4**).

Spearman's rank correlation revealed significant correlations between some items of presence and perceived environmental restorativeness, the four components of affect, and enjoyment (**Table 4**) including medium correlations between being there and

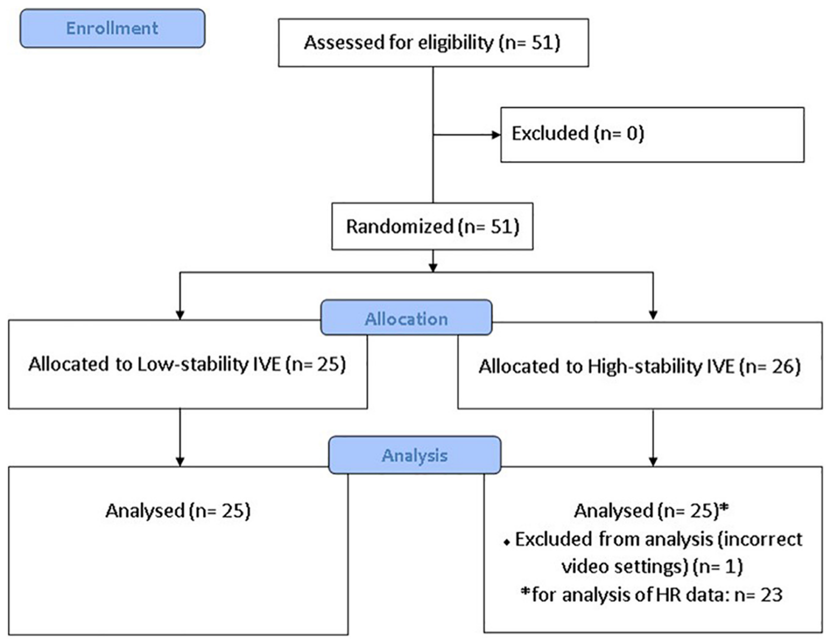

FIGURE 1 | Flow diagram showing participants enrolled, allocated to condition, and included in the analyses (Schulz et al., 2010).

three components of perceived environmental restorativeness and enjoyment, medium correlations between realism and one component of perceived environmental restorativeness and enjoyment, medium to high correlations between sense of reality and two components of perceived environmental restorativeness, a medium negative correlation between flatness and one component of perceived environmental restorativeness, and finally medium correlations between movement lag and the two negative components of the physical activity affect scale (**Table 4**). No significant correlations were found among the items of presence (**Table 4**).

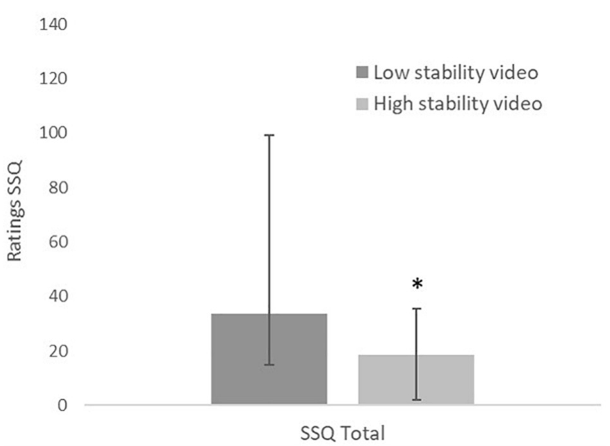

FIGURE 2 | Comparison of the severity of cyber sickness symptoms measured with the Simulator sickness questionnaire after exposure to a low- or high-stability 360° video. SSQ Total = Total score (n = 50; medians and IQRs). * = significant difference from low-stability video at the $p < 0.05$ level.

Psychophysiological Responses

The Wilcoxon signed-rank test showed that, after being exposed to the IVE, the participants in the LS condition had a significant deterioration of their affect state, with significant decrease in the ratings of Positive affect (Pre-exposure: Mdn = 3.67, IQR = 3.67–4.00; Post-exposure: Mdn = 3.33, IQR = 2.67–3.67; $Z = -2.735$, adjusted $p = 0.002$) and Tranquility (Pre-exposure: Mdn = 4.33, IQR = 4.00–4.67; Post-exposure: Mdn = 3.67, IQR = 2.67–4.33; $Z = -2.972$, adjusted $p = 0.021$) and a significant increase in the ratings of Negative affect (Pre-exposure: Mdn = 1.00, IQR = 1.00–1.33; Post-exposure: Mdn = 1.67, IQR = 1.00–3.00; $Z = -3.194$, adjusted $p = 0.014$). However, there was no significant change in ratings of Fatigue after the LS condition (Pre-exposure: Mdn = 1.67, IQR = 1.33–2.33; Post-exposure: Mdn = 2.00, IQR = 1.33–3.33; $Z = -2.338$, adjusted $p = 0.063$) as illustrated in **Table 5**. In contrast, no significant pre–post changes were observed in the HS condition for any of the components of affect (Positive affect, Pre-exposure: Mdn = 3.67, IQR = 3.00–4.00; Positive affect, Post-exposure: Mdn = 3.33, IQR = 3.00–4.00; Tranquility, Pre-exposure: Mdn = 4.33, IQR = 4.00–4.67; Tranquility, Post-exposure: Mdn = 4.00, IQR = 3.33–4.67; Negative affect, Pre-exposure: Mdn = 1.00, IQR = 1.00–1.67; Negative affect, Post-exposure: Mdn = 1.00, IQR = 1.00–1.67; Fatigue, Pre-exposure: Mdn = 2.00, IQR = 1.67–3.00; Fatigue, Post-exposure: Mdn = 1.67, IQR = 1.00–2.67; adjusted $p > 0.05$ for all comparisons). The Mann–Whitney U test of delta values for affect revealed significant differences between the two experimental conditions, with larger reductions of Positive

TABLE 3 | Spearman's rho correlation between total cyber sickness score (top row) and the items of presence[1], perceived environmental restorativeness[2] (fascination, being away, coherence, compatibility), affect[3] (positive affect, tranquility, negative affect, fatigue), enjoyment, HR, and background characteristics (n = 50).

	Total SSQ
Being there[1]	−0.14
Realism[1]	0.09
Sense of reality[1]	0.00
Awareness[1]	−0.04
Other people[1]	0.22
Noises[1]	0.19
Flatness[1]	0.02
Movement lag[1]	−0.15
Fascination[2]	−0.22
Being away[2]	−0.19
Coherence[2]	0.16
Compatibility[2]	−0.21
Positive affect[3] (Δ)	−0.39**
Tranquillity[3] (Δ)	−0.35*
Negative affect[3] (Δ)	0.50**
Fatigue[3] (Δ)	0.63**
Enjoyment	−0.48**
HRmean	0.11
HRmax	0.14
Sex	0.17
Age	0.04
BMI	−0.15
Weekly PA	−0.11

*BMI = body mass index. Weekly PA = weekly physical activity. Δ = delta values. *Correlation is significant at the $p < 0.05$ level. **Correlation is significant at the $p < 0.01$ level.*

affect (U = 174.5, adjusted p = 0.031) and larger increments of Negative affect (U = 146.5, adjusted p = 0.006) and Fatigue (U = 171.0, adjusted p = 0.028) after LS condition compared to HS. No significant difference between the two conditions was found for Tranquility (U = 226.0, adjusted p = 0.196). Similarly, the ratings of enjoyment after the HS condition (Mdn = 8.00, IQR = 6.00–9.00) were not significantly different compared to the LS condition (Mdn = 6.00, IQR = 5.00–7.00; U = 211.0, adjusted p = 0.136). No significant differences were found between the two experimental conditions for either average (LS: Mdn = 71.00, IQR = 64.00–77.00; HS: Mdn = 66.00, IQR = 62.00–77.00; U = 241.5, adjusted p = 0.551) or peak HR (LS: Mdn = 81.00, IQR = 72.00–91.00, p = 0.342; HS: Mdn = 76.00, IQR = 68.00–89.00; U = 252.0 adjusted p = 0.584).

DISCUSSION

The results of the present study demonstrate that the 360° video characterized by high camera stability induced significantly lower levels of cyber sickness compared to the 360° video characterized by low camera stability, which is in support of our main hypothesis. The lower levels of cyber sickness in the HS condition were not accompanied by a significant difference in presence, which contradicts our secondary hypothesis 1.1. For our last hypothesis (1.2), which postulated that a reduction in cyber sickness should be accompanied by an improved psychophysiological response, the results are partly in favor of the hypothesis as we found a more positive psychological response in the HS condition, but the physiological measures were similar between the two conditions. These results were obtained in two 360° videos that were perceived as having similar environmental characteristics as indicated by the similar values reported between the two conditions for the components of perceived environmental restorativeness. Furthermore, our exploratory correlation analysis revealed several possible pathways that can help explain the complex relation linking cyber sickness, environmental perceptions, and psychophysiological responses.

The total SSQ score was substantially lower after the HS condition compared to LS, which suggests that improving camera stability and thereby reducing camera oscillations reduce severity of cyber sickness symptoms in 360° videos. These results support the findings of previous provocation studies examining the impact of severe levels of oscillations on cyber sickness using a head-mounted display (Lo and So, 2001; Bonato et al., 2009). Lo and So (2001) found that a severe increase in either pitch, yaw, or roll increased symptom severity with no differences between axis in a head-mounted display with a limited field of view (48° horizontal, 36° vertical). Bonato et al. (2009) confirmed that severe levels of oscillations induce cyber sickness, and further revealed that oscillations along two different axes simultaneously increased symptom severity compared to single-axis oscillation in a head-mounted display with a 60° field of view. Our results are in line with the findings of Lo and So (2001) and Bonato et al. (2009) for 360° videos and further demonstrate that also low levels of oscillations influence cyber sickness. This notion is in line with the Sensory Conflict theory proposed by Reason and Brand (1975). As outlined in the introduction, it is believed that oscillations causes a sense of self-motion in the opposite direction of the oscillation, which causes a conflict between visual inputs and vestibular and proprioceptive inputs. In the present study, the HS condition produced less camera oscillation along all three axes, which may have reduced sensory conflict. This potential reduction in sensory conflict may explain the lower symptom severity after the HS condition. In contrast to symptom severity, the occurrence of cyber sickness was not significantly different between low and high stability. However, the effect was borderline significant even after applying the Benjamini–Hochberg procedure (p = 0.055), which suggests that scene stability may influence occurrence of cyber sickness and that the issue is worthy of further investigation.

The lower symptom severity (total SSQ score) and potentially less sensory conflict suggest that the HS condition should have induced higher levels of presence compared to LS, as a study by Slater et al. (1995) suggests that reduced sensory conflict may improve presence (Slater et al., 1995) and a recent review found an inverse relationship between presence and cyber sickness (Weech et al., 2019). This was not the case and participants reported similar levels of presence regardless of which video they had viewed. Early research in VR proposed the logical argument that lower levels of sensory conflict would lead to

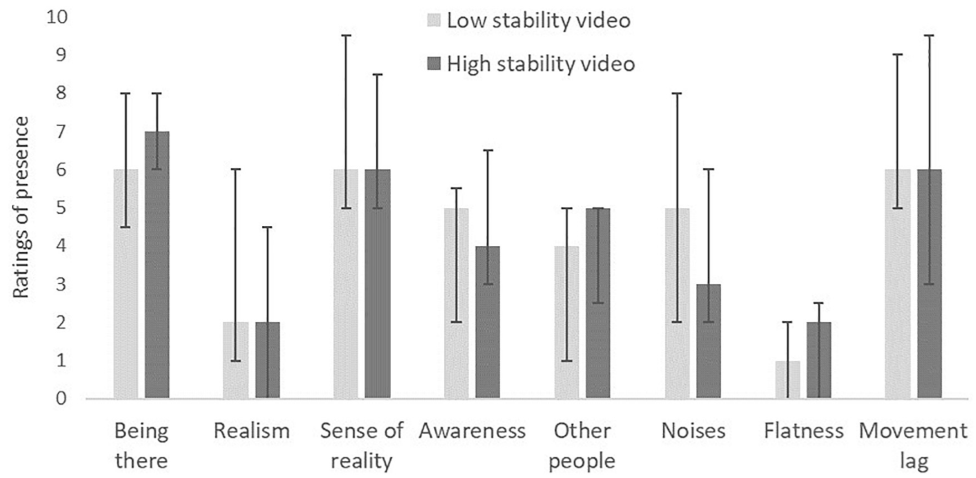

FIGURE 3 | Comparison of ratings of presence associated with exposure to a low- or high-stability 360° video (n = 50; medians and IQRs).

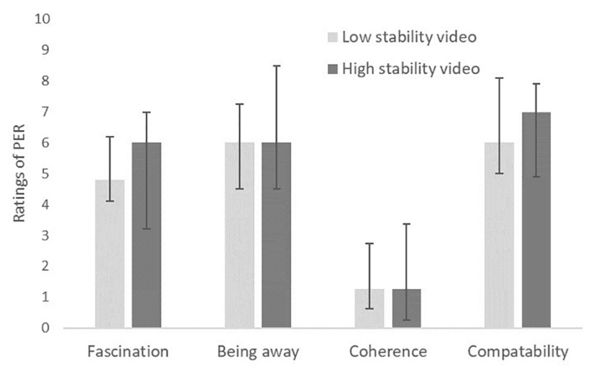

FIGURE 4 | Comparison of ratings of the four components of the perceived restorativeness scale (PER) associated with a low- or high-stability 360° video (n = 50; medians and IQRs).

higher levels of presence (Slater et al., 1995). This proposal is yet to be backed by rigorous scientific evidence, due to the challenge of directly measuring sensory conflict, but the idea has still carried on into more recent research (Weech et al., 2019). As stated above, we proposed the idea that the HS condition induced less sensory conflict compared to LS. These potentially lower levels of sensory conflict were not accompanied by higher levels of presence, which leads to one of two logical conclusions. Either lower levels of oscillations do not induce lower levels of sensory conflict or the idea that lower levels of sensory conflict increase presence is false. Unfortunately, the present study cannot make a definitive statement regarding this matter. However, our results definitively challenge the proposed relationship between cyber sickness and presence (Weech et al., 2019), as the between condition difference in cyber sickness was not accompanied by a difference in presence and there were no significant correlations between the two concepts. The lack of coherence with the conclusions by Weech et al. (2019) may have several explanations. Most importantly, Weech et al. (2019) acknowledges some limitations in the literature they reviewed: most of the literature had methodological limitations, such as limited sample size; most of the research identified supported an inverse relationship, but several papers also supported a positive relationship or no relationship; the review also identified several potential moderators of the relationship, such as sex, display factors, and context. In addition to the limitations in current research identified by Weech et al. (2019), it is also acknowledged that presence is a complex characteristic that is influenced by a multitude of factors, such as environmental interaction, synchrony of sensory stimuli, and fidelity of the virtual environment (Weech et al., 2019). Thus, it is possible that other aspects of the IVE, in addition to camera stability, must be improved in order to increase presence. Nevertheless, the present study does not support the proposed relationship between cyber sickness and presence and suggests that improved camera stability by itself does not result in higher levels of presence.

The fact that no differences were found between the HS and LS condition with respect to perceived environmental restorativeness is not surprising, as this measure is strongly dependent on the characteristics of the environments in which the 360° videos were filmed and should thus be interpreted as our efforts to reproduce highly comparable IVEs being successful. At the same time, this finding also suggests that, similarly to what was found for presence, the level of camera stabilization is unlikely to influence the viewers' perceptions of the virtual environment. Furthermore, the finding of the present study not only shows the paramount impact of camera stabilization in avoiding negative affective responses in the viewers of an IVE but also confirms the central role of cyber sickness in explaining such responses. It has to be stressed, however, that even though the HS condition was associated with significantly more positive affective responses than the LS condition, different from what we would expect from an *in vivo* situation, it was yet unable to induce significant improvements in the participants affect profile. In a previous study, we found in fact that an actual walk of the same duration in the same (real) environment where

TABLE 4 | Spearman's rho correlation between different components of presence (top row) and the components of perceived environmental restorativeness[1], affect[2], enjoyment, HR, and background characteristics (*n* = 50).

	Being there	Realism	Sense of reality	Awareness	Other persons	Noises	Flatness	Movement lag
Fascination[1]	0.40**	0.34*	0.26	0.13	0.04	−0.06	−0.31*	−0.14
Being away[1]	0.38**	0.26	0.46**	−0.17	−0.09	−0.10	−0.17	0.10
Coherence[1]	−0.04	0.03	−0.04	0.19	−0.09	0.05	−0.05	0.23
Compatibility[1]	0.36*	0.21	0.29*	−0.01	0.00	−0.09	−0.18	0.06
Positive affect[2] (Δ)	0.21	0.14	−0.10	−0.15	−0.03	−0.21	−0.12	−0.24
Tranquillity[2] (Δ)	0.06	0.21	−0.12	−0.11	−0.19	−0.13	0.25	−0.13
Negative affect[2] (Δ)	−0.07	−0.09	−0.06	0.12	0.07	0.04	−0.14	0.31*
Fatigue[2] (Δ)	−0.18	−0.16	−0.01	0.07	0.17	0.15	0.02	0.40**
Enjoyment	0.28*	0.30*	0.06	0.17	−0.09	0.17	−0.18	−0.19
HRmean	−0.09	0.20	−0.09	0.10	0.07	−0.08	0.13	−0.20
HRmax	−0.09	0.24	−0.09	0.09	0.09	−0.10	0.08	−0.21

*Δ = delta values. *Correlation is significant at the p < 0.05 level. **Correlation is significant at the p < 0.01 level.*

the 360° was filmed induced improvements in the participants' affect state, who reported a significant reduction of Fatigue and Negative affect after the walk as compared with before the walk (Calogiuri et al., 2018). This is in contrast with a previous study by Chirico and Gaggioli (2019), who found that the emotional responses to viewing a natural landscape *in vivo* or in form of IVE were not significantly different. In another study, Yu et al. (2018) compared participants' responses to viewing a natural vs. an urban setting in IVE and found some similarities to what would be expected *in vivo* (e.g., a reduction of negative emotions in the natural IVE as opposed to an increase in fatigue in the urban IVE). However, unlike trials *in vivo*, no difference between the two IVEs was observed with respect to physiological measurements (blood pressure, salivary α amylase, and HR variability). In the present study, the lack of influence of improved camera stability on presence (which remained somewhat limited) may also contribute to explain the inability of the virtual walk in the HS condition to provide psychophysiological outcomes similar to those expected *in vivo*. Presence is considered a key element of a successful IVE (Steuer, 1992) and research within various fields have linked an IVE's ability to induce feelings of presence to the ability to produce the desired effect of the specific IVE, e.g., within analgesia (Triberti et al., 2014) and treatment of anxiety and phobias (Ling et al., 2014; Botella et al., 2017). Since ratings of presence were similar in the HS and LS conditions, it was not surprising that the participants' psychophysiological responses were similar as well. Remarkably, and in line with our previous study (Calogiuri et al., 2018), the ratings of enjoyment and all components of the physical activity affect scale were moderately to highly correlated with total SSQ score, which emphasize the paramount role played by cyber sickness in modulating the viewers' affective responses to the IVE exposure. At the same time, significant medium correlations were also observed among enjoyment and two items of presence, namely, being there and realism. Based on the assumption that presence is a key element of an effective IVE, these findings suggest that the feeling of being there and realism were particularly important to the participants' rating of enjoyment. Similarly, three components of perceived environmental restorativeness were moderately to highly correlated with several items of presence, which suggest that improved feelings of presence are closely associated with the restorative value of nature IVEs.

TABLE 5 | Pre–post changes of the four components of affect.

	LS		HS	
	Mdn	**IQR**	**Mdn**	**IQR**
Positive affect				
Pre	3.67	3.67–4.00	3.67	3.00–4.00
Post	3.33**	2.67–3.67	3.33	3.00–4.00
Tranquility				
Pre	4.33	4.00–4.67	4.33	4.00–4.67
Post	3.67*	2.67–4.33	4.00	3.33–4.67
Negative affect				
Pre	1.00	1.00–1.33	1.00	1.00–1.67
Post	1.67*	1.00–3.00	1.00	1.00–1.67
Fatigue				
Pre	1.67	1.33–2.33	2.00	1.67–3.00
Post	2.00	1.33–3.33	1.67	1.00–2.67

*LS = low-stability video. HS = high-stability video. * = significant difference from pre-values at the p < 0.05 level. ** = significant difference from pre-values at the p < 0.01 level.*

It should be noted that there were considerable individual differences in the response to the IVEs presented in this study, especially for SSQ. This phenomenon is clearly illustrated by the size of IQRs and by the fact that three participants were unable to complete the 10 min of exposure to the LS condition due to high levels of cyber sickness, while others could view the same video without experiencing any symptoms of cyber sickness. Other studies have also reported large inter-individual differences in the extent to which different individuals respond to virtual environments in terms of susceptibility to cyber sickness (Akiduki et al., 2003; Curtis et al., 2015; Gavgani et al., 2017). These individual differences are not fully understood, but research suggests that genetics (Hromatka et al., 2015), sex (Munafo et al., 2017), visual acuity (Allen et al., 2016), and postural control (Munafo et al., 2017) may explain some of the inter-individual variability. In the present study, cyber sickness was not associated with sex, or any of the participants' background characteristics (age, BMI, and physical activity levels), which suggests that other factors caused the inter-individual variation. Further research that contributes to a better understanding of this phenomenon, and how it relates to the underlying causes of cyber sickness, is pivotal to shed more light on the issue of cyber sickness in relation to the application of IVE in green exercise research and practice, as well as and in the field of VR in general.

Strengths and Limitations

The primary strengths of this study relate to important characteristics of its design, such as blinding of participants and rigorous experimental procedure, which allowed strict control of most confounding factors such as expectations, carryover effects, temperature, noises, and lighting. A possible limitation was the fact that that the content of the IVEs was not exactly identical, as the videos were recorded at different times. Although measures were taken to make the content as similar as possible (see section "IVE Technology and Experimental Conditions"), some minor differences such as light conditions, ambient noises, placement of objects, and activities of other people passing by were unavoidable. These differences were considered minor and the impact on the outcome of the present study should be minimal, as corroborated by equivalent ratings of perceived environmental restorativeness in the two conditions. The sample size in the present study was calculated *a priori* for our main outcome (total SSQ score) and the statistical power should be satisfactory for this measure, but the sample size may still have been too small to obtain adequate power for the other measures included in this study. Generalizability of the findings might be limited, as our participants were healthy adults, and it is uncertain whether the findings apply to VR users with pre-recorded clinical conditions (e.g., severe sight deficiencies, infections of the vestibular system, or other health problems). The possibility of occurrence of type I error should also be considered for the correlation analysis given the relatively large amount of statistical tests performed. However, this analysis was meant to reveal potential associations to be considered for further investigation.

CONCLUSION

In the present study, we compared two different IVEs created by filming 360° videos with different stabilization techniques, leading to different amounts and frequency of small-magnitude oscillations. The findings show that a higher degree of scene stability in an IVE is paramount to reduce severity of cyber sickness symptoms, thus avoiding negative affective responses. Nevertheless, when comparing our findings to findings in studies of real nature, it is clear that even a highly stable IVE was ineffective in providing psychophysiological benefits equivalent to those expected *in vivo* (i.e., during a real nature walk). These findings not only demonstrate that technological advancements can improve the effectiveness of IVE in green exercise research and related areas but also show the complexity of the human–technology interaction and that more research and further technological advancement are needed before green exercise experiences can be sufficiently replicated in laboratory conditions.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. This study was registered in the Norwegian Centre for Research Data (reference number: 60451) and conducted in accordance with the Declaration of Helsinki. All patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SL and GC contributed to the study concept, study design, statistical analysis, and revision of the manuscript. SL conducted the experiments and drafted the manuscript. Both authors approved the final version of the manuscript.

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Working Desks as a Classification Tool for Personality Style: A Pilot Study for Validation

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We shape our surroundings; form the rooms we live in, so that we feel comfortable in them. This shows parts of our personality – it can be inferred from our environment. In this study, we created stereotypical desks embodying different personality styles and let 190 students choose which desk fits – in their subjective perspective – the most to their personality. To determine their personality style, the personality style and disorder inventory (PSSI) was used. Correspondence analysis (CA) was conducted to investigate the relationship between personality styles and choice of desks. Results did not show convergence of personality styles and desks. Contrary to the popular scientific idea, personality and creation of surroundings were not related; regarding our study, the relation is uninterpretable suggesting an individual's desk choice is not statistically dependent on one's individual's highest PSSI subscale. The study can be regarded as a pilot project for desk designs as classification tool for personality.

Keywords: personality styles, working desks, screening, correspondence analysis, PSSI

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INTRODUCTION

Symbolizations of Personality

Several studies report evidence, that personality is inferred from the outward appearance e.g., body shapes (Hu et al., 2018). This inference is done unintentionally and has its onset by the age of 3 years (Cogsdill et al., 2014). With regard to this correlation, the question arises if personal traits cannot only be inferred from body shapes but also from self-designed environment.

Over 30 years ago it was already postulated that expression of self-identity in working spaces arises in personalization (adding personal items to work space e.g., pictures or rearranging furniture), establishing a territory (one's own zone of control and influence) and in participation (being included in the decision process about designs in the office) (Sundstrom, 1987). 90% of employees personalize their working space (Wells and Thelen, 2002) in one or several of six major types of work-space personalization: friends and/or co-workers, the arts, activities, loved ones, intellect, and the senses. Correlating these categories with the Big Five personality traits, extraverted employees seem to display more items linked to friends, co-workers and intellect compared to introverted employees. Employees open to experience utilized more items related to arts and intellect to personalize their desk than employees closed to experience do. Both personality traits, Extraversion and Openness to Experience, were found to be linked to more personalization overall than people scoring high on Introversion and low on Openness to Experience. Employees who are less agreeable and conscientious possessed more items associated with activities such as sports and hobbies.

It has also been suggested, that people shape their environment reflecting how they define themselves (Gosling et al., 2002). One of the earliest theories connecting personal environment and an observer's perception was conceptualized by Brunswik (1956) in the Lens Model. It proposes two routes. The first route is the Cue Validity system (good information) describing that all perceived cues give a hint about the underlying construct, e.g., for office work it means that an organized desk refers to the underlying trait Conscientiousness (Gosling et al., 2002). The second route traces the observer's judgment inferred from the observable cue, e.g., the rating of the person's Conscientiousness, called Cue Utilization (meaning system). If both routes are intact, the judgment should converge with the underlying construct and result in high accuracy, but cues can also be a poor embodiment of the construct (route one) or can be misinterpreted (route two) resulting in low accuracy. Consequently, the Lens Model can be used to detect failure in perception either caused by operationalization of the construct or by error in inferring from observation. In the study of Gosling et al. (2002), observer's impressions were convergent among the different participants and often accurate to the underlying constructs as well – highest accuracy was found for Openness, lowest for Agreeableness inferred from different cues in displayed offices, and bed rooms.

Some other research also tried to explain the manner of relationship between the personality and the place of work of a person. It has been investigated if the cleanliness of an apartment (provided in fictional stories) would affect observer impressions of the resident: Specific traits like lower Conscientiousness, Agreeableness and greater Neuroticism were attributed to an owner of a messy working desk rather than a clean, organized desk (Harris and Sachau, 2005). In another study (Horgan et al., 2019), participants were assigned to sit in a researcher's office to judge the researchers Big Five traits afterward. Participants associated a messy desk with less Agreeableness and more Neuroticism compared to a nit and organized desk. In this study, it was differentiated between the severity of messiness but not between different designs of workspaces.

However, it has to be considered, that messiness is only one dimension while there are numerous variables that could be varied. According to Funder's (1995) Realistic Accuracy Model, messiness is not defined as a personality trait. Personality judgments depend on the availability of relevant cues for the specific personality trait. In our point of view, it seems necessary not only to vary the level of organization but also the design of the working space reflecting the personality style holistically.

In addition to research examining working environments, there are also studies focusing on different surroundings e.g., bedrooms (Perez-Lopez et al., 2017). Participants rated photos from real bedrooms in regard of sociodemographic variables and personality traits. They were able to identify certain traits from the cues of the surroundings, though it seemed to be easier to recognize younger peoples and females' rooms. The inferred personality of young people was described as open and conscientious while personality of older people was characterized as low emotional stable for women and as low agreeable for men. Personality traits were moreover distinguished in symbolic and functional objects. While Extraversion and Agreeableness were categorized to rather symbolic objects; Responsibility, Openness to Experience and Emotional Stability were clustered in functional personal belongings. Although this study was divided in two levels regarding the displayed environment, a holistic level (the bedroom as a whole) and a micro-level (only single cues present in the bedroom), the construct personality was still regarded unidimensional and not holistic as a specific set of certain traits.

To summarize, people shape their environment reflecting how they define themselves, linking working space to personality traits as well (Gosling et al., 2002; Harris and Sachau, 2005; Horgan et al., 2019). While these studies focused on Big Five trait characteristics, we will try to extend this approach to personality styles seen as a whole set of traits. The concept of personality style is more general including the concepts trait, type, and temperament (Eriksen and Kress, 2005). Following the underlying theory of the PSSI (PSI theory), personality is determined by a characteristic network of feelings, needs, cognitive systems, and processes of self-regulation of an individual. Personalities can be differentiated by the dominance and differentiation of each of these components. Each personality style is linked to specific pattern of interaction between affective, cognitive, and volitional systems. Hence, the theory is able to capture different aspects of personality, first the inner nature of an individual (personality), second the interactions with the environment (system), and third the interplay between both levels (interaction) (Kuhl et al., 2006). After reviewing the literature, there are no studies investigating the relationship between personalization of an environment and personality style of a person seen holistically instead of regarding only isolated traits. This paper presents a research looking for the relation among these ideas; concretely we expect personality styles to offer more elucidation into people's choice of environment.

Hypothesis

We hypothesize that personality styles – regarded as a whole set of different personality traits – can be objectified in working desk. Choosing a desk will be driven by an identification process corresponding to the personality style of each participant. As the Lens Model proposes, extracting cues representing the own personality traits should increase the validity by only allowing errors in the first route. By only associating items to their subjective perspective of their own personality, error of inference will not be measured as they would be in a third person perspective. Personality styles measured with the PSSI will following to this correspond to the choice of desk embodying the same personality style. We suggest that the desk choice was preferred proportionally more often by participants scoring highest on that particular PSSI subscale.

MATERIALS AND METHODS

Participants

One hundred and ninety students (82 males and 108 females) aged between 18 and 23 years were tested for the experiment. The study was conducted in accordance with the Declaration of Helsinki for the Guidelines of Ethical Considerations. Ethical approval for this study was not required following the conditions outlined by the German Research Society (DFG) where research carrying no additional risk beyond daily activities does not require Research Ethics Board Approval. We communicated all considerations necessary to assess the question of ethical legitimacy of the study.

Material

Working Desks

According to the DSM-V (American Psychiatric Association, 2013) eleven desks were created. The choice of items for each desk was rated by three psychologists, and items were only chosen in case of independent agreement of all three psychologists. The items represent different traits of a personality style, labels of items can be seen in **Figure 1**. To better understand the link between personality traits of each personality style and chosen items, two examples for each desk creation are shown in (**Appendix Table S1**).

The creation of desks must be seen as pilot project not yet validated in former studies.

PSSI

The PSSI is a well validated self-report instrument, developed and revised by Kuhl and Kazen (2009) to measure personality styles as non-pathological equivalents for personality disorders as proposed by the DSM-IV-TR (American Psychiatric Association, 2009). It consists of 140 items distributed to 14 subscales each containing 10 items. Internal consistencies are given (above 0.8) and construct validity is acceptable for clinical and non-clinical behavior (Kuhl and Kazen, 2009). Further information about items and quality criteria are shown in (**Appendix Table S2**) and about factor replication analysis in (**Appendix Table S3**).

Avoidant: Helmet (1), Deo and sun cream (2), Curtains covert (3), Knigge course/Behavioural norms (4), Organized, unremarkable desk not offering reason for criticism (5)

Histrionic: Colourful items associated with fun (1), Feather (2)

Narcissistic: Bottle of expensive wine (1), Desk moved away from neighbour (2), Mirrors (3), No photos of friends/No personal items (4), Apple hardware (5)

Borderline: Shrine with flower, photo and candle of important relationship (1), Block with'fuck off!!!' written on it (2), Vodoo puppet (3), ripped photos a couple and two friends (4), I love you heart (5), Hair tie (6), Razor blades with blood (7), Handkerchiefs (8)

Paranoid: Fence (1), Complaint box (2), Tel. number of private detective (3), Tel. number of Attorney (4), Conspiracy belief articles (5)

Schizoid: Desk moved away from other desk (1), Empty sterile desk/no items (2), No personal items (3)

Antisocial: Current relationship/cheating tinder (1), Deck of Cards (2), Bottle of beer (3), Razors blades with blood (4), Knives (5), Tinder match (6)

Passive-aggressive: Chaotic, messy desk (1), Outstanding reparations (2), Dead flower (3), Usage of neighbour desk (4), Numerous post-its with unfullfilled tasks (5), Expired periods for books (6)

Dependent: Childlike toys (1), Schedule for tasks helping other people (2), Photos of friends (3), Co-chair (4), Key hang board of friends reserve keys (5)

Schizotypal: Broken glass and dirty dishes (1), Desk moved away from other desk (2), Items with no use/head holder/electronic garbage (3), Neglected abandoned shabby desk/leaf stone (4), Spy glass (5), Antennas (6), Old Shoe (7)

Obessive-compulsive: Organized boxes for bills with different amounts (1), To do list (2), Key hang board (3), Arranged order of items (4), Text markers in several colours (5), No personal items (6), Call forwarding if not at work (7) Memorising etiquettes for turning of light etc. (8), Desinfaction spray and papers (9), Weekly schedule (10)

FIGURE 1 | Designed working desks according to DSM-V symptoms.

Procedure

Participants were tested in a group session. The students reported relevant demographic data, before completing specific personality information. In regard of personality, each student had to choose a desk, shown in a sequentially order on the screen, that reflects their personality most suitable. After choosing items representing their personality, participants completed the PSSI.

Statistical Analysis

In accordance with Hu et al. (2018), who investigated which personality traits are inferred from certain body shape features, we used correspondence analysis (CA) to determine whether personality style is related to the choice of the corresponding desk. CA is a statistical method that transforms cross-tabular data, i.e., observations of two or more categorical variables, into a more intuitive, graphical representation reducing the number of dimensions similar to principal component analysis (Greenacre, 2017). This means that the inertia for each row and column, i.e., the divergence of the observed frequencies in the contingency table from the marginal frequencies, constitutes the magnitude of a dimension in a multidimensional space. First, a new, oblique dimension is extracted from this space representing maximal inertia of the rows and columns. Second, another dimension is extracted, orthogonal to the first, representing a maximum amount of the remaining inertia which has not been represented yet by the first. This pattern continues until the number of extracted dimensions is equal to the number of rows or columns (whichever is smaller) minus one (because then, all of the data's inertia is represented). Finally, the dimensions are displayed two at a time as axes of a coordinate system establishing a so-called map.

The map resulting from the CA displays orthogonal dimensions that represent maximal amounts of inertia or divergence from independence present in the data. Rows and columns of the initial contingency table are then projected onto the same map as points, with higher positive or negative loadings on a dimension indicating a larger amount of inertia of a row or column being explained by this dimension. When two rows (or two columns) have similarly extreme (or diametrically opposed) loadings on a dimension, they diverge in a similar way from independence, i.e., they differ from the marginal distribution in the same categories. When a row and a column commonly load on a dimension in such a way, this specific row differs from other rows in that it has proportionally less or more observations in this specific column, and vice versa. Contentwise interpretation of the dimensions relies on the rows and columns with high loadings or, when marginal frequencies vary widely, on those with high contributions (Greenacre, 2017; Hu et al., 2018). Conversely, rows and columns that lie close to the origin of the map, i.e., have no high loadings on any dimension, do not differ proportionally over the columns or rows, respectively.

Applied to our study, this means if a PSSI subscale (columns) and a desk choice (rows) commonly load onto the same dimension then participants that have their highest score on this subscale proportionally preferred this desk choice more often compared to the whole sample in general. In accordance with our hypothesis, we expect PSSI subscales and their corresponding desk choices to load commonly onto the same dimensions. In order to transform the data into an appropriate form, we categorized each participant, labeling them according to their highest score among the PSSI subscales. Participants with two or more subscales sharing the highest score were excluded from this analysis leaving 175 of 190 participants.

In addition to the visual interpretation of the CA map, we performed a χ^2 independence test on the contingency table. We examined the stability of the principal inertias and of the PSSI labels and desk choices in the multidimensional space using multinomial sampling (Greenacre, 2017). For the principal inertias, 9999 contingency tables are resampled from the multivariate marginal distribution of the original contingency table, simulating the distribution under the null-hypothesis of independence. On each of these resampled tables, we performed a CA and extracted the inertias for all dimensions. The proportion of inertias per dimension (including the inertias from the original data) that are equal or greater than the inertias in the original data represent the probability that the observed inertia resulted under the assumption of independence and can be compared to the significance level (Greenacre, 2017). For the stability of the loadings of the labels and desk choices on the dimensions, we resampled 9999 contingency tables from the multinomial distribution given by the cell probabilities in the original contingency table. CAs on all resamples provide simulated coordinates, i.e., loadings on the dimensions, for each point that are projected onto the map as supplementary points. Repeatedly forming and removing convex hulls of these point clouds for each original point separately until approximately 95% of points remain yield 95% confidence regions for the point coordinates (Greenacre, 2017). A convex hull consists of the outermost points of a point cloud which, when connected by straight lines, enclose all other points. A small 95% confidence region signifies high stability of the loadings of a point on the respective dimensions, which can be interpreted with more confidence. And if the confidence region for example includes

TABLE 1 | Inertias of the ten dimensions.

Dimension	1	2	3	4	5	6	7	8	9	10
Inertia	0.206	0.162	0.122	0.073	0.044	0.030	0.021	0.006	0.001	<0.001
% Inertia	31.0	24.1	18.3	11.0	6.1	4.6	3.1	0.9	0.2	<0.1
(Cumulated)	(31.0)	(55.3)	(73.6)	(84.7)	(91.2)	(95.8)	(98.9)	(99.8)	(100.0)	(100.0)
p-value	0.205	0.080	0.065	0.304	0.568	0.455	0.287	0.720	0.834	0.604

p-values were calculated with the bootstrap procedure described above.

the origin then this would be indicative of the respective PSSI label not being associated with any desks or the respective desk not being associated with any labels.

We performed statistical analyses in general in RStudio version 1.1.463 (RStudio Team, 2016) using R version 3.5.2 (R Core Team, 2018) and CA in particular using the FactoMineR package version 1.41 (Lê et al., 2008). The global significance level is set to 5%.

RESULTS

The χ^2 independence test indicates no deviation from independence, $\chi^2(100) = 116.2$, $p = 0.128$, suggesting that no desk choice was preferred proportionally more often by participants scoring highest on a particular PSSI subscale. As the CA builds on the column and row profiles, each of which sums to one, all of the inertia in the data can be represented by as many dimensions as the number of rows or columns (whichever is smaller) minus one. **Table 1** shows the inertias of the resulting ten dimensions. The first dimension has an inertia of 0.206 that, compared to the theoretically maximum inertia per dimension, which is one, is relatively low. The following dimensions accumulate even less inertia leading to a small $\Phi^2 = 0.49$ and *Cramer's V* = 0.049. The *p*-values resulting from the bootstrap procedure are all above 0.05, indicating that no inertia is significantly higher than one would expect under the assumption of independence. Because of this, only the first two dimensions are explored visually.

Figure 2 shows the loadings of the columns, i.e., the PSSI labels, on the first two dimensions along with convex hulls encircling 95% confidence regions for those loadings derived from the bootstrap procedure on the stability of the points in the multidimensional space. **Figure 3** shows the same for the rows, i.e., the desk choices. All 95% confidence regions contain the origin, indicating that none of the points loads stably on the first two dimensions. Additionally, all of the confidence regions overlap in an almost concentric manner, suggesting that the points do not differ reliably in their loadings on the first two dimensions, which accumulate over half of the inertia in the data.

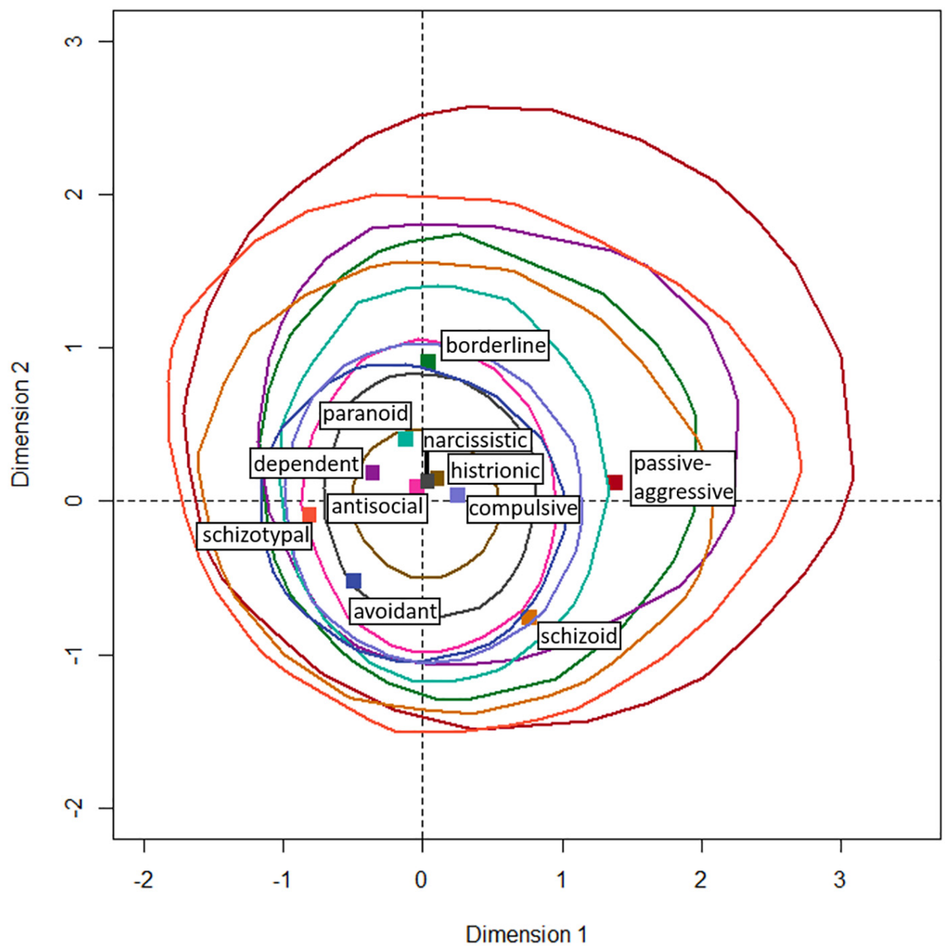

FIGURE 2 | Loadings on the first two dimensions that together represent 55.3% of the inertia for the PSSI labels (columns). Dashed lines emphasize the origin. Solid colored lines indicate 95% confidence regions for the stability of the point coordinates in the multidimensional space. These result from bootstrapping using the cell probabilities of the contingency table.

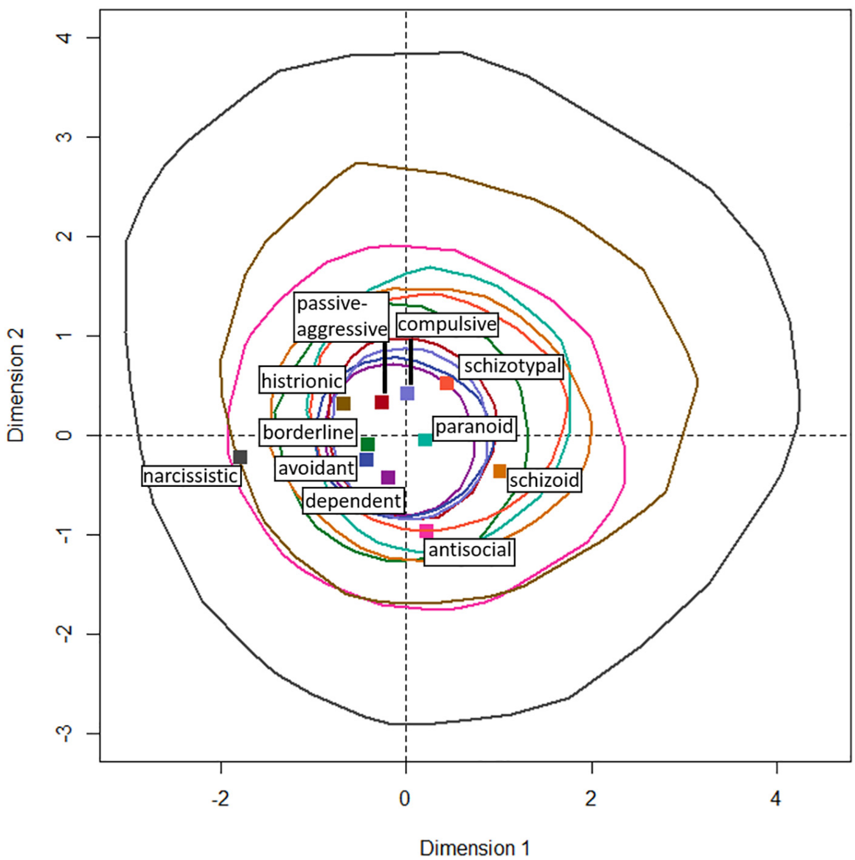

FIGURE 3 | Loadings on the first two dimensions that together represent 55.3% of the inertia for the desk choices (rows). Dashed lines emphasize the origin. Solid colored lines indicate 95% confidence regions for the stability of the point coordinates in the multidimensional space. These result from bootstrapping using the cell probabilities of the contingency table.

All these findings indicate a very low amount of inertia, i.e., little divergence from independence, in the data. This makes the dimensions uninterpretable and suggests that an individual's desk choice is not statistically dependent on that individual's highest PSSI subscale.

DISCUSSION

Summary and Interpretation

The results of our pilot study emphasize the multifaceted nature of the construct personality. Desks and self-reports show different visual patterns and only three personality styles could be embodied from our desks. Concluding, our desks do not represent the personality styles as a whole set of traits measured by the PSSI. Several reasons can be given for the lack of correspondence between personality style and desks. Although the selection of the items was chosen by three experienced psychologists working in this field; the appropriateness of items could have been re-evaluated by other non-participating psychologists. In case of mismatch of items and personality traits problems regarding construct validity might be caused. In addition, interpretation of our items as objects or symbols might offer different possible inferences compared to verbally presented behavior or attitudes as it was operationalized in other studies (e.g., fictional stories, Harris and Sachau, 2005). This might be the reason why the lack of results in this study is contrary to some previously published work. Also, former studies have focused on single personality traits of personality constructs such as the Big Five (Gosling et al., 2002; Harris and Sachau, 2005; Hu et al., 2018; Horgan et al., 2019) whereas we measured personality styles as a holistic set of single traits trying to illustrate a complete person in an environment. It seems to be easier to illustrate single, isolated traits like Consciousness or Agreeableness compared to a whole set of traits forming a specific personality style. Lastly, the type of environment – working space – might be more strongly influenced in its creation by other factors, whereas living rooms or bodies seem to be closer linked to personality variables (Gosling et al., 2002; Hu et al., 2018).

Limitation and Future Research

It could be argued, that our items might represent symptoms of disorders rather than personality styles as we aimed them to. If this were the case, the examined sample – healthy students – would not have been appropriate for evaluating our tool.

In a clinical sample, the desks might not have been perceived as extreme as it was the case in our investigation apparently. Participants were cautious picking desks with eye-catching items, the narcissistic desk for example was only chosen by one person. Consequently, by examining students, not personality disordered patients; the sample is possibly limiting the degree and number of symptoms one might show; our approach could have taken a too clinical perspective for a healthy sample.

Another critical aspect of our classification tool is the lack of visualization of some symptoms. This can be explained by the difficulty of illustrating certain personality traits, as well as by the complexity of the symptoms leading to overlooking single items on a desk. Some items have more salience than others do, causing an unintended weighting of symptoms. However, our findings are in line with Wells and Thelen (2002), who also found personality to have a very small correlation with personalization in workspaces. One might only be able to infer that a person is extraverted (more personalization) or introverted (less personalization) than recognizing a personality holistically from the environment. Also, degree of personalization might be driven and limited by the company's personalization policy and an employee's status and workspace. Gosling et al. (2002) provides reasons for the lack of relationship between offices and personality. In comparison to personal living spaces, people are more limited in decorating their offices because of company guidelines. Additionally, individuals in a working environment are concerned about the positive and professional image they convey, both voluntarily and because of extrinsic pressure and norms. As a result, their actual preferences and personalities might not be observable in their working desks rather corresponding to social norms. Offices might also be ecologically limited, typically only provided to spent time of work there. Other environments offer more space for free-time activities revealing cues for personality traits. In regard of the sample, students could be in a crucial phase of developing the own identity. Resulting identity issues might lead to a particular proneness of self-expression. These explications can be applied to our study as well.

Concluding, further studies have to be done, investigating the most appropriate personality measurement to catch this specific situation i.e., as working desk space. To confirm the absence of the relation it might be worth to run another study including other well proven personality questionnaires like the Big Five in addition to the PSSI as well as other spaces representative of a person. Future studies could complement this direction of research by transferring our idea to other surroundings closer linked to personality traits than a working environment. Particularly, surroundings or behavior that everyone can relate to would be useful (e.g., own bedroom, car). However, this interesting idea presented here should be followed further.

CONCLUSION

Our tool to screen personality styles could not be validated yet. Desks measure different constructs than represented by the PSSI. The popular scientific idea composing a relationship between environment and personality could not be confirmed; the relation seems to be far more complex; personality style cannot be transformed in corresponding living spaces. However, our pilot study adds to an important field of research, which is neglected nowadays: investigating built environments. Nowadays, Environmental Psychology is immersed on natural settings, and mainly focused on climate change. With this study, we would like to contribute to the importance of self-accomplishment in our closest surroundings: The buildings we live in.

DATA AVAILABILITY STATEMENT

The datasets analyzed in this manuscript are not publicly available. Requests to access the datasets should be directed to corresponding author.

ETHICS STATEMENT

Ethical approval was not provided for this study on human participants because the study was conducted in accordance with the Declaration of Helsinki for the guidelines of ethical considerations. Ethical approval for this study was not required following the conditions outlined by the German Research Society (DFG) where research carrying no additional risk beyond daily activities does not require Research Ethics Board Approval. We communicated all considerations necessary to assess the question of ethical legitimacy of the study. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AR contributed to the conceptualization and writing of the manuscript. MS calculated the results. BG planned the study. PJ initiated the study, contributed to the conceptualization, supervised and corrected the study.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02588/full#supplementary-material

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PERSPECTIVE
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A "Cookbook" for Vulnerability Research

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There is a growing need to facilitate the interdisciplinary study of the relationship between the environment and human health and well-being. It is increasingly recognized that vulnerability is a key construct allowing discipline-specific research questions on these topics to be meaningfully contextualized. However, there is little consensus regarding the meaning of the concept of vulnerability or how it can best be utilized in research studies. In this perspective article, we use the metaphor of a "cookbook" to review promising trends in vulnerability research and to make this body of research accessible to a multi-disciplinary audience. Specifically, we discuss a selection of "recipes" (theoretical frameworks), "ingredients" (vulnerability domains), "cooking tools" (qualitative and quantitative methods), and approaches to "meal presentation" (communication of results) drawn from vulnerability studies published in the past 15 years. Our aim is for this short "cookbook" to serve as a jumping-off point for scholars unfamiliar with the vulnerability literature and an inspiration for scholars more familiar with this topic to develop new ways to navigate the tension between locally-specific assessments of vulnerability and attempts at standardization. Our ultimate take-home message is that the specifics theories and methods used in vulnerability research are less important than attention to what we see as the 3 'T's of *transparency*, *triangulation*, and *transferability*, and to efforts to make vulnerability research both "place-based" and comparable.

Keywords: vulnerability, health, socio-ecological systems, place-based, comparative, theory, methods

INTRODUCTION

Multiple disciplines, including public health, anthropology, economics, and ecology, concern themselves with the health, well-being, and livelihoods of marginalized communities (1–3). It is increasingly recognized that vulnerability is a key construct allowing discipline-specific research questions on these topics to be meaningfully contextualized. Thus, the concept of vulnerability can build bridges for cross-disciplinary communication and research (4) and potentially provide a mechanism for connecting science and policy (5). However, there is little consensus on "best practices" in vulnerability research (6) and obstacles remain in developing measures that are applicable across different contexts (7). Still, scholars interested in vulnerability aim to advance approaches that facilitate comparability (8), while remaining attentive to the fact that vulnerability is place-based and "inescapably contextual" [(9), p. 508].

With these goals and limitations in mind we present the beginnings of a "cookbook" for interdisciplinary vulnerability research that highlights the 3 'T's of *transparency, triangulation, and transferability*. Extending the metaphor of the cookbook in the first section of this article we discuss four commonly used theoretical approaches in vulnerability research (different "recipes"). We do not present a one-size fits all solution but review these theories to encourage researchers to be *transparent* in the framing of their work and to aid in pinpointing a number of domains ("ingredients") for vulnerability assessments, discussed in the second section. In the third section, we pinpoint methods ("cooking tools"), which can measure these domains and use a few short examples that highlight the *triangulation* of qualitative and quantitative methodologies to facilitate research that is attentive to local contexts and comparable. In the final section, we discuss "meal presentation" or ways to make our research results "appetizing" and *transferable* to a range of stakeholders.

Thus, we aim for this short "cookbook" to serve a dual purpose. On the one hand, we envision it as a jumping-off point for scholars unfamiliar with the vulnerability literature. On the other, we hope our perspective will inspire scholars more familiar with this topic to develop new ways to navigate the tension between locally-specific assessments of vulnerability and attempts at standardization. Our review is not exhaustive. Rather, we focus on recent trends in the vulnerability literature with the intention of catalyzing continued thinking about balancing richness and replicability in future research.

BACKGROUND

Before diving into the meat of this "cookbook" we note that despite decades of vulnerability research, there is little consensus regarding the meaning of this concept (10). This is reflected in the variety of terms related to vulnerability including procedural/contextual vulnerability (11), outcome vulnerability (12), structural vulnerability (13), social vulnerability (14), and participatory vulnerability (15). Further complicating interpretations of this work is the fact that there are significant conceptual overlaps between vulnerability and related terms such as exposure, susceptibility, coping, resilience, adaptation, transformation, and sustainability (16, 17). Despite these conceptual overlaps, vulnerability research remains divided along multiple theoretical fracture lines (18). This can make for confusing reading that risks alienating researchers from different disciplines and stakeholders outside academia.

Although reviews of vulnerability research exist (4, 6, 18), we see a space for an updated and succinct summary of this work. To do this, we utilized academic search engines such as Science Direct and Google Scholar with key words such as "vulnerability," "socio-ecological systems," "health," and "well-being" to identify relevant papers. We constructed a matrix with cells for the aim of the paper, methods, definition of vulnerability, theoretical or conceptual models used, domains measured, themes, communication of results, and policy applications. We reviewed more than 50 articles published in the last 15 years focused on vulnerability research allowing us to identify the "recipes," "ingredients," "cooking tools," and "approaches to meal presentation" for our "cookbook."

Section 1: "Recipes"

Any theoretical framework for the study of vulnerability should address the complex, non-linear interactions existing between social, cultural, political, ecological, and biophysical processes (19). However, a critique of the concept of vulnerability is that it is so broad, so inclusive, that it becomes a momentous task to consider all the intellectual dimensions involved (20). Therefore, we advocate selecting a theoretical framework that aligns with the strengths and goals of the researcher. This is especially important considering that many papers do not mention the application of a particular theoretical framework (17), even though different framing prioritizes the production of different knowledge and responses (12).

Below we discuss four theoretical perspectives employed in recent empirical and review papers addressing vulnerability, global change, and health. Each paragraph contains an accessible definition, key terms associated with each approach, commonly addressed topics, and applications.

Risk-Hazard Approach

The risk-hazard approach examines the impacts of a hazard on an exposed entity (21) and defines vulnerability as a function of exposure, sensitivity, and adaptive capacity (22). Common hazards include famines, floods, drought, seismic events, and technological failures (23). Associated key terms include biophysical, disaster, natural hazards, perturbations, pressure-and-release (PAR) model (24), exposure, risk, and sensitivity. This approach has been used in the development of a range of vulnerability indices (25–27) and widely applied in a number of recent studies [see (9, 26, 28–30)]. It is particularly helpful for engineers, economists, and development professionals in disaster research (6).

Political-Ecology Approach

In contrast to the "geocentric," risk-hazard approach the "anthropocentric," political-ecology approach (6) argues that hazards are not natural, but rather dependent upon societal factors (31). Examples of socially-conditioned hazards include pollution, poor housing and infrastructure, social fragmentation, and trade liberalization (32). Decision-making power is central to this model (33) and vulnerability can be defined as the risk created by exposures to unequal power relationships and hierarchical social orders (13). Key terms associated with this approach include inequality, injustice, power, marginalization, exploitation, discrimination, structural, and historical factors. Unsurprisingly, this interpretation is of interest to scholars concerned with historic, social, economic, and environmental inequalities (34) from a range of disciplines [see (11, 13, 31, 35, 36)].

Resilience Approach

Resilience is defined as the ability of a system to absorb shocks and regenerate after a disturbance. In this school of thought, vulnerability can be defined as "the attributes of persons or groups that enable them to cope with the impact of disturbances" [(37), p. 237]. A key idea is that of "adaptive capacity" or the ability of the exposed entity to mitigate impacts, take advantage of new opportunities, and cope with novel stressors. Associated key terms include agency, systems-thinking, social structure, coping, adaptive capacity, social conditions, thresholds, and persistence. A resilience approach is particularly useful in determining policy-oriented interventions for dealing with uncertainty, future change, and adaptive capacity (38) and is typically utilized by scholars in interdisciplinary programs [see (17, 39–41)].

Sustainable Livelihoods Approach

While a resilience model takes a "systems-approach," a sustainable livelihoods approach starts with a "bottom-up" perspective to understanding how resources are mobilized on a local level (5). A livelihood is defined as the capabilities, assets, and activities necessary to support a means of living (42) and is considered sustainable if it does not undermine the natural resource base (43). In a sustainable livelihoods approach, researchers examine human, social, natural, physical, and financial capitals (44). Similarly, to the previous perspectives, vulnerability can be defined as what may happen to a specific population under conditions of particular risks and hazards. The difference is an emphasis on vulnerability as being *predictive* as it should aid in directing interventions or supporting livelihoods (45). This approach has been used successfully as the basis for development programs and practices (46).

In several recent papers (5, 26, 31, 40, 44, 47, 48), the sustainable livelihoods approach functioned as a bridge between theory and methods by enabling scholars to pinpoint a number of relevant and measurable domains related to the concept of vulnerability. In the next section, we discuss considerations for selecting "ingredients" for a vulnerability assessment and use the five capitals of the sustainable livelihoods as an example of connecting theory to measurable domains.

Section 2: "Ingredients"

Going from a theoretical framework to deciding what to measure in a vulnerability study can be particularly daunting as the range of potential topics is extremely broad. In **Table 1**, we use the sustainable livelihoods approach to identify "ingredients" or domains and measurable sub-domains. **Table 1** is not a prescriptive list of "ingredients," but rather an example of how to translate abstract concepts into measurable aspects of vulnerability research.

This process can be extended to the risk-hazard, political-ecology, and resilience approaches through a review of each body of literature and highlights two take-away messages. The first message is the 'T' of *transparency,* or being clear about the research process (49), especially in regard to the framing that leads to the selection of particular indicators. The second message relates to the 'T' of *transferability,* or the study's potential to be valuable across contexts and situations (49). One way to do this is to question whether the values and ideas of the primary investigators are valid or relevant in a particular field-site by eliciting the voices of the people with whom you work before moving forward with measurement (50). With this in mind, in the next section, we discuss "cooking tools," or qualitative and quantitative methods, which can yield data that is both "place-based" and amenable to comparison and replicability.

Section 3: "Cooking Tools"

In the words of Veland et al. (11) researchers need methods enabling us to "see with both eyes" (p. 316) to capture what it means to be vulnerable from a local and scientific perspective. We present **Table 2** as a drawer of "cooking tools" (qualitative, quantitative, and mixed methodological approaches), presented with key terms, related methods, and references, that we believe can help scholars select approaches that capture both angles.

While we separate **Table 2** into qualitative, quantitative, and mixed method categories, many of the studies found in each of the groupings utilize *triangulation*, or the use of multiple sources of data and conceptual frameworks (49). One example is rapid rural appraisals, which utilize small, multi-disciplinary research teams who employ mixed methods "in an intensive, iterative, and expeditious manner" [(53), p. 1069]. For example, Berrang-Ford et al. (53) used semi-structured interviews, key informant interviews, future story-lines, biographies, and photovoice to understand vulnerability to climate change among the Batwa of Uganda. Using the risk-hazard approach and basic quantitative analyses, they identified common themes in their qualitative data that shed light on exposure, sensitivity, adaptive capacity, and related health outcomes in this context. They found that climate change interacted with socioeconomic factors to increases risk for water and food insecurity, exposure to disease vectors, and weather-related stressors (53).

In the Berrang-Ford et al. (53) study, participant voices were integrated into the research. However, Fazey et al. (15) advocate for even deeper integration of community members in the research process with the aim of building local capacity and enhancing equity to reduce vulnerability. For example, Fazey et al. (15) worked collaboratively with local organizations in the Solomon Islands to train members to conduct vulnerability assessments. Periods of formal reflection were facilitated among primary researchers, research assistants, and community members to encourage engagement with challenges such as fluctuating global markets and a growing population. This highly participatory process facilitated co-learning between researchers and community members, generated high quality information amenable to academic analysis, and increased the confidence of local people to address issues with food insecurity, health, and resource availability.

By integrating community members into research design and data collection, deeply participatory research can keep the results of the study in the hands of local people, allowing them to use it for communications, political lobbying, or further investigation of the challenges they face. In the final section, we expand on the value of transferability (italicized), by discussing ideas for creatively communicating research results to a multi-stakeholder audience to enhance the impacts of vulnerability investigations.

TABLE 1 | "Ingredients" for consideration: livelihood capitals, domains, and sub-domains.

Livelihood capitals	Domains	Measurable sub-domains
Human capital	Education, knowledge, skills, capacity to work, health, nutrition, capacity to adapt	Highest educational qualification, dependency ratio, occupational training, perceived health, costs for medical treatment
Social capital	Social connections and networks, religious/cultural beliefs, local knowledge, participation in decision-making	Memberships in local, national, and international organizations, expenditures on social events, traditional ecological knowledge
Natural capital	Biodiversity, land, water, aquatic resources, trees and forest products, wild foods and fibers, ecosystem services	Quality of the land possessed, area under cultivation, area of woodland or fruit trees, access to water for irrigation
Physical capital	Infrastructure, tools, and technology	Type and expenditure for housing, distance to nearest road, tools and equipment for production, traditional technology, shelter, water supply and sanitation, energy, communications
Financial capital	Savings, credit, debt, remittances, pensions, wages	Gross household annual income, household savings, and ownership of livestock

TABLE 2 | "Cooking tools" for consideration: qualitative, quantitative, and mixed methods.

Approach	Key terms	Methods/indices	References
Qualitative	Place-based, context-dependent, bottom-up, multi-stakeholder, participatory, dialogue-oriented, reflexive	Participant observation, interviews, focus group discussions, community workshops, future story-lines, biographies, photovoice	(11, 15, 20, 51–55)
Quantitative	Comparative, standardized, indices*, scales, repeatable	Survey, census, livelihood vulnerability index, index of vulnerability, social vulnerability index, hunger, and climate vulnerability index	(8, 10, 56–61)
Mixed	Hybrid, integrated, multi-method, equal status design, mixed priority design	Socioecological matrices, integrated assessment map, rapid rural appraisal, participatory action research, citizen science	(9, 56, 62–64)

**see Hinkel (7), Barnett et al. (65) for caution in the application of indices.*

Section 4: "Meal Presentation"

While our "chefs" may have used tried and true recipes, with delicious ingredients, and state-of-the-art cooking tools, if the meal does not look appetizing, no one will want to eat it. What we mean is that if researchers do not think about presenting their results in an accessible format, the larger body of stakeholders who can benefit from this work will not consume the results.

With this in mind, a key challenge for successful *transferability,* or successful uptake of the work, is to communicate results *with*—not *to*—stakeholders (20). This requires scholars to think about how they can align their take-home-messages with local norms (54). For example, Veland et al. (11) used ceremony, storytelling, talk of dreaming, and the *logic of country* to communicate their results to the Aboriginal Australian peoples with whom they worked. Indeed, jargon-free language and alternative formatting, such as storytelling, graphic displays, and mapping, can make research results accessible to a range of stakeholders. These stakeholders can then use the information for educational initiatives, mitigation programs, and even humanitarian relief distribution programs (66).

Such efforts can be "low tech and low cost." In their work in rural villages in the Philippines, Gaillard et al. (67) helped residents make 3D town maps with dough and plywood to identify the most vulnerable locations and homes. Data from these maps were entered into geographic information system databases and digitized for use by local scientists and governments, integrating local and scientific knowledge, as well as bottom-up and top-down disaster risk management (67). Finally, advances in communication and information technologies, such as innovations in the use of tablets, smartphones, and "smart applications" can close the gaps between citizens and scientists, making research more collaborative, transparent, and efficient (68).

In summary, there are many creative ways to conduct vulnerability research that is theoretically-informed, "place-based," and amenable to comparison. A final example that portrays how a scholar can use the "cookbook" approach presented here is Tallman's (56) Index of Vulnerability (IoV). This quantitative index was inspired by Leatherman's (34) articulation of a "space of vulnerability," which used a political-ecological approach to examine the intersection of poverty, hunger, nutrition, and health. Tallman (56) used this "recipe" in conjunction with the "cooking tools" of participant observation, interviews, and focus group discussions with Awajún community members in the Peruvian Amazon to identify the "ingredients" of food insecurity, water insecurity, social support, social status, and healthcare access as important to understanding vulnerability in this context. Scores on the IoV increase for each life domain where the individual falls into a "high risk" category. This approach makes the IoV standardized but also malleable to local contexts, as scholars can choose which measure of each life domain is most appropriate for their study population. In research among the Awajún, the IoV was associated with measures of stress, perceived health, energetic reserves, depressive, and somatic symptoms (56). These results were shared with stakeholders through an interdisciplinary conference bringing together scholars, government officials, indigenous leaders, and non-governmental organization representatives to discuss vulnerability among indigenous Amazonian peoples. What emerged from this event was that if stakeholders feel they own the process (i.e., participating in design and data collection), information (i.e., seeing their views represented), and materials (i.e., being involved in development and diffusion of key messages and visuals), they will be more likely to share the findings widely, creating a ripple of impacts in different arenas.

CONCLUSION

In this perspective article, we aimed to mitigate the, at times, overwhelming complexity of vulnerability scholarship by increasing the accessibility of this work using the metaphor of a "cookbook." Specifically, there is an abundance of confusing and overlapping terminology in vulnerability research, which necessitates that researchers are *transparent* about the meanings and usage of theoretical frameworks, methods, and indicators in their work (7, 69). Additionally, there are a number of studies that utilize deeply participatory methods but lack explicit theoretical models—and vice versa (15). *Triangulation* can be among theory and methods, data and investigators (14) or among sources, methods, and other investigations (53). This allows "different facets of problems to be explored, increases scope, deepens understanding, and encourages consistent (re) interpretation" [(49), p. 843], which can yield vulnerability research that is "good science" from a methodological and ethical perspective. In conclusion, vulnerable people and places are often excluded from decision-making, power, and resources (4), despite the fact that local knowledge can provide key insights into understanding vulnerability and adaptation (54). Thus, we need to think about ways that our research can be *transferable* to multiple stakeholders by accommodating alternative research questions and methods of inquiry (11) and creating effective relationships for knowledge sharing. Ultimately, we hope that attention to these issues will yield research that is rich, replicable, and amenable to facilitating social justice and human dignity for the most vulnerable among us.

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PT led the writing of this manuscript. AV-V, GS-M, GL, AR-P, LB-V, SH, and VP-S all contributed to the development of the ideas within the manuscript and substantially contributed to revising it throughout the writing process.

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The Role of Social Relational Emotions for Human-Nature Connectedness

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Little is known about the psychological processes through which people connect to nature. From social psychology, we know that emotions play an essential role when connecting to others. In this article, we argue that social connectedness and connectedness to nature are underpinned by the same emotions. More specifically, we propose that *social relational emotions* are crucial to understanding the process through which humans connect to nature. Beside other emotions, kama muta (Sanskrit: being moved by love) might play a particular crucial role when connecting to nature. Future research should consider the role of social relational emotions in human-nature relationships.

Keywords: connectedness to nature, social relational emotions, social connectedness, kama muta, awe, well-being, sustainability, human-nature relationship

"When one tugs at a single thing in nature, he finds it attached to the rest of the world"
– John Muir

INTRODUCTION

A positive relationship between humans and the natural world has been shown to be cross-culturally essential to sustain both human well-being and the well-being of the environment. This claim is supported by evidence of health-related and emotional well-being benefits from human interaction with nature (Hartig et al., 2014; McMahan and Estes, 2015) as well as its effects on pro-environmental attitude and behavior to address environmental sustainability issues (Geng et al., 2015; Ives et al., 2018; Rosa et al., 2018). In this context, a substantial body of literature has explored the human relationship and orientation toward nature. Among the conceptualizations are *nature relatedness* (Nisbet et al., 2009), *inclusion of nature in self* (Schultz, 2002), *emotional affinity toward nature* (Kals et al., 1999), and *connectedness to nature* (Mayer and Frantz, 2004). Some of these concepts tap into cognitive appreciation of being embedded in nature, while others focus on the emotional attachment or address material dependence on nature (Ives et al., 2017). Despite their differences, all of the concepts seem to agree on same core phenomenon: a relatively permanent connection to nature on the individual level (Tam, 2013; Capaldi et al., 2014). Psychometric scales used to measure this, such as the *nature relatedness scale* (Nisbet et al., 2009) or the *connectedness to nature scale* (Mayer and Frantz, 2004), are all highly correlated with one another (Tam, 2013). Accordingly, we will not distinguish between the different concepts in this paper, and we will refer to *nature connectedness* as an umbrella term.

Nature connectedness has recently been shown to be a predictor of human well-being (Capaldi et al., 2014), as well as pro-environmental attitudes and behavior (Mackay and Schmitt, 2019). Explanations addressing the general question of why humans connect to nature are for the most part theoretically rooted in the Biophilia Hypothesis. First coined as a term by Fromm (1964) and later expanded by Wilson (1984), the Biophilia Hypothesis originates from the evolutionary notion that humans depend on their natural environment. It is claimed that this dependence evolved into a predisposition to be cognitively and emotionally attracted to nature and to affiliate with it (Kellert and Wilson, 1993). In this sense, the Biophilia Hypothesis provides a basis for an interdisciplinary research agenda to understand the general motivation of humans to connect to nature. However, it leaves the question open how such feelings of connectedness to nature are instantiated.

KNOWLEDGE GAP AND AIM OF THE PAPER

We need to understand and investigate the specific pathways that lead to nature connectedness in order to provide possibilities for it to occur. In this scope, psychological mechanisms have been stated to be central when examining the routes to nature connectedness (Zylstra et al., 2014; Lumber et al., 2017). Research from social psychology demonstrates that connecting to others is closely tied to emotional processes (Fiske et al., 2019), but little attention has been given to the emotional mechanisms that presumable enable and mediate connecting to nature (Milton, 2002). Consequently, the present paper adds explanatory value to understanding human-nature interaction by stressing that specific emotions play an important role for connectedness to nature, not simply a side-effect or outcome. To the best of our knowledge, this is the first paper to suggest that social relational emotions have an important role to play in the process of connecting to nature.

In the next sections, we first discuss the relationship between social connectedness and connectedness to nature and explain why both concepts are most likely underpinned by the same emotional mechanisms. We then describe the function of emotions for the process of connecting to social others and highlight the potential of social relational emotions in this scope. In the third paragraph of the paper, we present specific research examples on the role and impact of these emotions in the scope of connecting to nature. We conclude by addressing the significance and implications of social relational emotions for future research.

CONNECTEDNESS TO NATURE AND SOCIAL CONNECTEDNESS

Humans are social beings and therefore have a fundamental need to relate (Baumeister and Leary, 1995; Dunbar and Shultz, 2007; Fiske, 2018). This need is often satisfied by socially connecting to others such as the partner, family or friends. However, we know that people also socially relate to animals, deceased ancestors, deities, abstract entities such as countries, humanity as a whole, or even imagined collectivities in order to meet their need to relate (Fiske, 2004; McFarland et al., 2012). Likewise, ecopsychologists have pointed out that the need to relate can be satisfied by feeling connected to nature (Schultz, 2002; Baxter and Pelletier, 2019).

While social psychology has mainly focused on connections between humans, ecopsychology has tried to understand the connection between humans and the natural world. Although little research has specifically investigated the relationship of these two concepts, the literature points to the conceptual similarities between social connectedness and connectedness to nature. First, Kals et al. (1999) and Mayer et al. (2009) demonstrated that like human connections with other humans, positive experiences with nature can lead to an emotional affinity and cognitive identification with nature. Second, both relationships have similar basic features such as commitment (Davis et al., 2009) and inclusion of the other (nature or other human beings) in the self-concept (Schultz, 2002). Third, several studies have found relations between measures of social connectedness and connectedness to nature. For instance, Howell et al. (2011) and Howell et al. (2013) found significant positive correlations between *social connectedness*, framed as social well-being (Keyes, 1998) and the *connectedness to nature scale* by Mayer and Frantz (2004), the n*ature relatedness scale* by Nisbet et al. (2009), and the *allo-inclusive identity nature subscale* by Leary et al. (2008). Finally, the notion of *being connected* itself is a psychological one, which is mediated by culture, context, and experiences (Mesquita et al., 2016). Therefore, it is plausible to hypothesize that connecting to other human beings and connecting to nature are underpinned by the same general psychological mechanisms, which include cognitive, emotional, and behavioral processes. We focus here on specific emotions that play an essential role in connecting to others.

SOCIAL RELATIONAL EMOTIONS – THEIR FUNCTION FOR SOCIAL CONNECTEDNESS

In this paragraph, we discuss what kind of emotions facilitate social connectedness and how. Emotions, in general, play a crucial role in our daily life as they influence how we think and behave (Ekman and Davidson, 1994; Scherer and Ekman, 2009). Emotions can be defined as rather short-lived, object-directed and high in intensity, in contrast to moods, and for the purpose of this paper are best described by the approach of appraisal theory (Moors, 2010; Moors et al., 2013). Typically, humans experience emotions more strongly when events are relevant to their current needs, aims, motives, values, norms, attachments, beliefs, or expectations (Frijda, 1986; Lazarus, 1991; Scherer, 2005). Furthermore, emotions can make experiences more memorable (Reisberg and Heuer, 1992). In this sense, emotions are functional, guiding us in adaptive responses to social relational opportunities and challenges (Fiske, 2002, 2010). For instance, although often perceived as negative, the primary function of shame, grief, guilt, and embarrassment is to establish, regulate, and maintain social relationships and social positions relative to others (Bastin et al., 2016, p. 457). Due to the specific underlying function of establishing, regulating and maintaining relationships, these emotions can be categorized as *social relational emotions*.

More recently, emotions with positive valences have also received scientific attention. These are awe (Keltner and Haidt, 2003; Shiota et al., 2007), admiration (Onu et al., 2016), gratitude (McCullough et al., 2001; Ma et al., 2017), compassion (Nussbaum, 1996), and moral elevation (Haidt, 2003; Pohling and Diessner, 2016). All of these emotions seem capable of boosting a sense of connection with others and can, therefore, be categorized as *positive social relational emotions*. For instance, Stellar et al. (2017) highlighted that emotions like awe, gratitude, and compassion are powerful proximal determinants of prosocial action. According to the authors, it is through prosocial tendencies, that these emotions (termed by the authors as *self-transcendent emotions*) bind individuals to others.

In this context, we highlight the potential of one specific positive emotion, kama muta, (Sanskrit: being moved by love; Seibt et al., 2017; Fiske et al., 2019; Zickfeld et al., 2019), which may be the most crucial social relational emotion in connectedness. Holding a new-born baby in your arm, surprisingly seeing a loved one again after a long time, or unexpectedly receiving a great kindness are typical example of moments in which people experience kama muta. In vernacular English, kama muta is often described as being *moved* or *touched*, while the elicitors may be called *heartwarming* (Fiske et al., 2019). The primary appraisal involved in kama muta is experiencing a sudden intensification of communal sharing. A number of studies suggest that kama muta has evolved (biologically and culturally) to regulate communal sharing relations (Seibt et al., 2017; Schubert et al., 2018). Communal sharing, one out of four relationships humans use to coordinate their social interactions, is the foundation of relationships in which people feel shared identity, are motivated by unity, share resources according to need and ability or signal and commit to being one by assimilating each other's bodies (see: Relational Models Theory: Fiske, 1991, 1992, 2004). While kama muta is often evoked by the perception of a sudden intensification of a communal sharing relationship with another human being, the theory is not restricted to it. It explicitly suggests that people may feel kama muta when suddenly intensifying communal relationships with an animal, deity or even an abstract entity such as the earth or the cosmos. Therefore, kama muta is likely to play an important role in nature connectedness.

THE ROLE OF SOCIAL RELATIONAL EMOTIONS IN NATURE EXPERIENCES

In this section, we are raising awareness for the fact that aspects of social relational emotions have been associated with psychological inspired research on nature experiences for the last 50 years, but rarely investigated empirically. By pointing to some current empirical research in this field, we highlight the potential that social relational emotions offer for understanding the gateways to nature-connectedness and the associated outcome variables such as well-being.

Although not explicitly conceptualized as such, social relational emotions have long been recognized in the philosophical literature on environmental ethics. Naess (1977), who builds his theoretical considerations regarding deep ecology upon the ideas of Spinoza, views emotions to be fundamental to the complex inter-relationships that the natural world consists of. Early philosophically-inspired researchers looking into psychological aspects of connecting experiences in nature tended to ascribe emotional characteristics to nature experiences without separating them from other aspects of the experience. For instance, based on the concept of *peak experiences* by Maslow (1964), a study with a sample of 1,000 Americans showed that 82% of the participants indicated that they had experienced the beauty of nature in a deeply moving way (Wuthnow, 1978). A study by DeMares (2000) found similar emotional responses. According to the interview respondents, the encounter with cetaceans led to feeling connected with the animal and was sometimes described as a life-changing peak experiences. Expanding on the concept of peak experiences, the ecopsychologist Davis (1998) proposed the term *transpersonal experiences in nature*, which includes the experience of peace, joy, love, support, inspiration, and communion. According to the author, those are aspects of nonreligious spiritually. Later, Trigwell et al. (2014) identified such non-religious spirituality as a mediator of nature connectedness and eudaimonic well-being. Additionally, Marshall (2005) refers to *mystical experiences* in which people feel that the natural world evokes a sense of unity, knowledge, self-transcendence, eternity, light, and love. The notion of emotions as part of some form of spirituality is widely noted in the literature when trying to explain processes of nature connectedness. However, a more recently published paper by Lumber et al. (2017) investigated whether the nine values of the Biophilia Hypothesis, which represent a combination of different values and emotions, mediate nature-connectedness. Through two online surveys (n = 321) and one walking intervention (n = 72), they found that contact with nature, emotion, meaning, compassion, and beauty are pathways to improving nature connectedness. Another recent research project by Anderson et al. (2018) used daily diary methods to look at distinct emotions and their mediating role in nature experience for the outcome of well-being. In their first study, they found that awe experienced by 72 military veterans and 52 young people from underserved communities while white-water rafting, above other positive emotions measured, predicted increases in well-being, and reduction of stress-related symptoms after one week. In the second study, they showed that the nature experiences of 115 undergraduate students during their everyday lives led to more awe, which mediated the effect of nature experience on improvements in well-being. Additionally, gratitude and awe each mediated the effect of nature experience on daily life satisfaction.

In sum, research on social relational emotions and nature-connectedness presents itself as relativity vague and indicates that it includes a mix of social relational emotions, often labeled as *spiritual* aspects. Such a theoretical framing makes it challenging to scientifically investigate emotional processes. However, English-speakers' descriptions of experiences as *deeply moving* or even *love* might represent instances of the kama muta emotion. Moreover, despite some weaknesses in the methodology, single empirical examples reveal that emotions in general, and compassion specifically, could be important for the sense of nature connectedness. Furthermore, the literature suggests that social relational emotions such as awe and gratitude play a direct role in well-being that result from contact to nature.

CONCLUSION AND IMPLICATIONS FOR FUTURE RESEARCH

Understanding the emotions that facilitate and strengthen a sense of nature-connectedness has the potential to inform moves to increase human well-being and to foster pro-environmental attitudes and behavior. Social-relational emotions, especially kama muta, seem to be salient in experiences of connection with nature. This has five implications.

First, future research should investigate empirically, how, singly or in combination, of social relational emotions such as awe, compassion, gratitude, moral elevation, and kama muta effect connectedness to nature. Researching emotions and relationships is complex. This and the fact that we propose a new area of research invites multiple methodological approaches. While systematic approaches are required to explore the structure of the experienced phenomenon on the individual level, for instance, by applying the descriptive phenomenological method (Giorgi, 2009), systematic approaches on a larger scale are essential to allow for generalization of findings. For example, collecting data though the mobile experience sampling method (mESM) could address the fact that emotional states are brief experiences at particular moments in time. Applying mESM by using smartphone technology is a method of continuous recording of people's daily life in real time to assess emotional states on a within and between level (Pejovic et al., 2016). In comparison to traditional self-report, the ESM method is less subject to biases introduced by recall and retrieval processes (Shiffman and Stone, 1998; Stone et al., 1998).

Second, it is important to recognize that every experience, including its underlying emotions, is culturally situated and culturally informed. Connectedness to nature is fostered by cultural models of *nature* (Wohlwill, 1983). This makes it essential to conduct research across cultures that consider how cultural conceptions of nature enable, limit, and shape social relational emotions. If theory should guide practice, future research in this area should accordingly be based on established and cross-culturally applicable theory-based emotions, such as kama muta, which is labeled with a Sanskrit term in order to avoid the confusions of vernacular lexemes (Fiske, 2019). Validated measures should be used to facilitate comparison among studies as well as the generalization of findings. For instance, for kama muta, there exists the KAMMUS-Two scale developed by Zickfeld et al. (2019) across a variety of contexts, in 19 countries and 15 languages. A well-established and valid questionnaire for gratitude is the Gratitude Questionnaire-6 (GQ-6) (McCullough et al., 2002), and for the emotion awe, the Awe Experience Scale (AWE-S) (Yaden et al., 2019).

Third, given Anderson et al.'s (2018) finding that experiencing the emotion of awe in nature predicts well-being, it will likely be fruitful to explore whether other social relational emotions mediate the effects of nature connectedness on well-being and pro-environmental attitudes and behavior. Positive emotions initiate a broader range of thoughts and actions than negative emotions do and have in general been identified as affording well-being and happiness (Diener and Seligman, 2004; Cohn et al., 2009). However, emotions like grief or guilt about injury to the environment or loss of nature may have substantial effects on people's sense of responsibility for nature and may foster care for it. Thus, it would be particularly interesting to compare the effects of negatively perceived social relational emotions, such as grief or guilt, with positively perceived social relation emotions such as compassion, awe, or gratitude.

Fourth, despite the fact that current research emphasizes the benefits of direct engagement with nature, it simultaneously points to mounting evidence that physical contact with nature is decreasing (Rosa et al., 2018). In this context, Chirico et al. (2018) compared virtual exposure to nature and actual contact with nature. The results indicate that while browsing nature photographs or watching a nature documentary are likely to improve mood, getting outdoors, and connecting directly with nature was associated with better well-being benefits. Future research needs to address the question of how to maintain and adapt the possibilities for social relational emotions and human-nature connectedness to take place when technology is the medium to provide virtual exposure to nature. Studies in this area can be realized through experimental settings using virtual reality.

Finally, we have argued that social connectedness and connectedness to nature are underpinned by the same social relational emotions. However, do these emotions satisfy the human needs to relate in the same way or to the same degree when connecting to nature compared to connecting to other human beings? In other words, are there social relational

IMAGE 1 | Connecting to nature. Norway, 2018. Picture taking by Joanna Stüber.

emotions and qualities of relating or belonging that can only or more easily be enabled through experiences in nature, or through experiences with other humans? Future research should address such questions in order to provide guidance to practical application such as psychological or environmental therapy for attachment disorders, depression, anxiety, and other conditions.

FINAL REMARKS

Above we quoted John Muir, "When one tugs at a single thing in nature, he finds it attached to the rest of the world". Grasping any aspect of nature affords possibilities to ameliorate the well-being of individuals, communities, and the environment – because as we grasp a bit of nature, in turn nature tugs at our heartstrings (**Image 1**).

AUTHOR CONTRIBUTIONS

EP conceptualized and wrote the first draft. AF and TS contributed with advice. All authors revised the final manuscript.

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Minimum Time Dose in Nature to Positively Impact the Mental Health of College-Aged Students, and How to Measure It: A Scoping Review

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Background: Across the U.S., college and university students exhibit high levels of stress, anxiety, depression, and other mental health issues. While counseling, medications and, in more severe cases, hospitalization are all appropriate treatments for such conditions, an increasing body of evidence has demonstrated that spending time in nature can provide tangible benefits for mental health and well-being. The aim of this study was to define a "dose" of time in nature that could be prescribed to college-age students, as a preventative and supportive mental health and well-being intervention. The specific objectives of this scoping review were thus: to define the minimum amount of time in nature that results in positive impact on mental health and well-being for college-aged students; to describe the types of engagement with nature that elicited the impact; and to describe and explore the most commonly used measure of effect pre- and post-time in nature.

Methods: This scoping review was conducted following the PRISMA-ScR Checklist. A review protocol was developed but not registered. Fourteen bibliographic databases were searched and all results were blindly screened using established inclusion criteria. All titles and abstracts were screened by at least two reviewers, a third being used as a tie-breaker if needed. Studies were included if: subjects were of average college age; they examined a treatment of time (hours or minutes) in nature; they examined change in measures of mental health and well-being pre- and post-exposure; they compared participants across at least two environments; the study was published in English or French; and if the study was $<$20 years old.

Results: Initially, 11,799 titles were identified and once de-duplicated, 10,917 titles were screened. One hundred fifty-five papers were given full text reviews, of which 14 studies were included in this review. In summary, 13 of the 14 papers explicitly noted that the participants were college students. Two-thirds of the studies ($n = 10$) took place in Japan. One study took place in Sweden, and the remaining studies took place in the United States (n = 3). These studies show that, when contrasted with equal durations spent in urbanized settings, as little as 10 min of sitting or walking in a diverse array of natural settings significantly and positively impacted defined psychological and physiological markers of mental well-being for college-aged individuals. Within the included studies, 22 different measures were used to assess the effects of nature doses on mental health and well-being.

Conclusions: This review provides time-dose and activity-type evidence for programs looking to use time in nature as a preventative measure for stress and mental health strain, and also demonstrates opportunities in six specific foci for more research in this area.

Keywords: nature, mental health, well-being, stress, time dose, university, college

INTRODUCTION

Rationale

While the U.S. continues to hold the top ranking among university systems worldwide, American college and university students are experiencing unprecedented levels of stress, depression, and other psychologically-debilitating conditions (Williams and Leahy, 2018). The causes of this collective emotional distress are many, from competition for grades, to technologically-prompted isolation, to severe financial pressures (Eagan et al., 2015).

There is ample evidence of the current public health crisis of student well-being on American campuses. Within the 12 months prior to a 2017 survey, responding college students reported more than average or tremendous stress (67%); feeling overwhelming anxiety (61%); hopelessness (51%); and 13.2% had been diagnosed or treated for depression or anxiety (American College Health Association, 2017). These high levels of mental health strain are reflective of the general population, in which one fifth of the global population experienced mental illness sometime in the previous 12 months (World Health Organization, 2017).

Public health and healthcare staff and administrators at colleges and universities in the U.S. are aware of these challenges and recognize that their institutions' educational missions cannot be achieved without attending to the mental and behavioral health concerns of their students. While they are taking steps to address these needs, counseling and intervention demands can be overwhelming (Association of University and College Counseling Center Directors Annual Survey, 2017; USA Today, 2017). A recent study of 112 presidents and student affairs leaders at 2- and 4-year post-secondary education institutions found that mental health issues among enrolled students was the respondents' number one health concern (The Chronicle of Higher Education, 2017). In 2014, 94% of Counseling and Psychological Services (CAPS) center directors indicated that the number of students with severe psychological problems continues to increase on their campuses, yet almost two-thirds of students who meet the criteria for depression do not get help, and only about four percent of students with a history of alcohol use disorder receive services of any kind (Douce and Keeling, 2014). In fact, 76% of college counseling directors reported that they had to reduce the number of visits for non-crisis patients to cope with the increasing overall number of clients (Gallagher, 2015).

While the most debilitating cases of student psychological problems, such as suicidal ideation, self-laceration, and severe substance abuse, must be addressed through comprehensive approaches including counseling, prescription medication, and possible hospitalization, multiple studies have demonstrated the beneficial upstream preventative effects of spending time in natural settings on emotional well-being and cognitive acuity (Maller et al., 2006; Van den Berg et al., 2007; Bratman et al., 2012; Cox et al., 2017; Hansen et al., 2017; Antonelli et al., 2019). And, while four recent review articles summarize and reinforce the mental health and well-being benefits from time in nature (James et al., 2016; Crouse et al., 2017; Hansen et al., 2017; Antonelli et al., 2019), there is no clear summary of how much time is needed to elicit these positive results, particularly among college-age students. Thus, as public health practitioners and educators with interest in supporting student mental health and well-being, we sought to examine the available evidence to make informed decisions related to campus-based interventions in the U.S. This included identifying what accessible and sustainable dose of time in nature is required to elicit a positive impact on the mental health and well-being among people of college-age, and to describe what types of engagement with nature (i.e., passive vs. active engagement) provide said impacts.

Theoretical Basis

A variety of theories of how nature impacts human health have been advanced over the past 150 years. In 1865, Olmsted reflected on the role of natural scenery in psychological restoration: it "employs the mind without fatigue and yet exercises it; tranquilizes it and yet enlivens it; and thus, through the influence of the mind over the body, gives the effect of refreshing rest and reinvigoration to the whole system" (quoted in: Nash, 2014).

In recent decades, several theories have been proposed to explain the mechanism by which time spent in nature promotes an improved psychological state. *Attention-restoration theory (ART)* developed by Kaplan and Kaplan in the 1980s, postulates that prolonged use of directed (voluntary) attention, as demanded by the complex and technologically-driven modern world, causes mental fatigue and associated loss of focus and increased irritability. Experiences in the natural world, according to this theory's proponents, promote a restorative environment which allows the brain's directed attention to rest and recover from the rigors of problem solving (Kaplan, 1995).

In contrast to ART, *stress-reduction theory*, developed by Ulrich et al. in the 1980s, argues that natural environments facilitate reductions in physiological arousal following stress, rather than the restoration of directed attention (Ulrich et al., 1991). This theory posits that, in response to external stressors, shifts occur in the body's cardiovascular, skeletomuscular and neuroendocrine systems. Time spent in natural settings, or even viewing natural scenes through a window or on a screen, can result in positive changes in physiological activity levels and then lead to a more positively-toned emotional state (Hartig et al., 2014). Landscaped settings, such as those found at botanic gardens or parks, have also been shown to have a role in stress reduction (Kohlleppel et al., 2002; Grahn and Stigsdotter, 2003). These findings are consistent with other studies that have found that anything from a grassland to a waterfall can provide the restorative mental health benefits of nature (Van den Berg, 2008; Hansen et al., 2017; Antonelli et al., 2019).

Current levels of stress and poor mental health among students at institutions of higher learning are acknowledged to be unacceptably high, and time spent in nature has been shown to offer relief from stress, depression, and lack of focus (Lau and Yang, 2009). The particular natural experience an individual seeks can vary from a seemingly untouched forest to a fully designed landscape. Much research has indicated that it is the time spent in nature, not the "nature of the nature," that is most critical (Wolf and Robbins, 2015; Bratman et al., 2019).

A few recent studies have focused specifically on this question of appropriate time dose in nature. One study examined the effect of nature experiences on reductions in salivary cortisol and alpha-amylase concentrations, two biomarkers of physiological stress. These researchers found that a nature duration between 20 and 30 min, three times per week, was most efficient (Hunter et al., 2019). A second study looked at weekly time in nature, comparing individuals who spent various intervals to those who spent no time in nature. These researchers found that spending at least 120 min in nature per week led to significantly higher self-reports of positive health and well-being (White et al., 2019). While neither of these studies focused on college-aged students, they provide evidence of the feasibility of prescribing specific time doses in nature.

Objectives

The objectives of this study were to comprehensively scan the available literature to (1) identify what *accessible and sustainable dose of time in nature* appears to elicit a positive impact on *mental health* in people of college-age, (2) describe what types of engagement with nature (i.e., passive vs. active engagement) provide said impacts, (3) describe the most commonly used measures of effect, and (4) identify the strengths and gaps in the literature (methods and understanding) to guide future research.

Accessible and sustainable doses of time in nature were defined as minutes and hours in types of natural areas that could be easily and routinely reached from a college campus by any student, regardless of means; this excluded, for example, multi-day outdoor retreats or experiences in "exotic" places such as deep wilderness, mountain tops, etc. Mental health was defined as psychological elements linked to general well-being (e.g., low stress, lack of depression, happiness, ability to focus). While the term "nature" may strictly be defined as "all the animals and plants in the world and all the features, forces, and processes that exist or happen independently of people, such as the weather, the sea, mountains, reproduction, and growth" (The Cambridge Dictionary Online)[1], in practice, much of the research views nature more expansively as including elements of the built or designed environment. For the purpose of this review, nature was defined as green spaces, including manicured urban parks, urban woods, and relatively undisturbed natural sites.

Research Question

This study looked to define how much time, doing what activities in nature, has a positive impact on mental health among college-age students, and what methods can be used to measure effect.

METHODS

Study Design

A scoping review approach was used to guide this study, allowing the research team to identify and review available and relevant literature, to surface and describe themes and gaps, as a step toward more focused research.

Participants, Interventions, Comparators

Subjects of interest for the review included people of average college age (no younger than 15, no older than 30), and interventions of interest for the review included a defined/measured period of time in nature engaged in a defined activity. Measures of interest for the review included changes in biological and/or self-reported measures linked to mental health and well-being.

Scoping Review Protocol

This scoping review was conducted following the PRISMA (preferred reporting for items for systematic reviews and meta-analyses, http://www.prisma-statement.org/) checklist for standards for systematic reviews. Part-way through the implementation of this scoping review, the PRISMA-ScR Checklist was published, and this scoping review has been adapted to follow these newly published guidelines (Tricco et al., 2018). A scoping review protocol, available upon request, was developed but not registered.

Search Strategy and Data Sources

Bibliographic databases were searched on December 15, 2016, including Web of Science (All Databases, which included BIOSIS Citation Index, BIOSIS Previews, CAB Abstracts, Current Contents Connect, Data Citation Index, Derwent Innovations Index, FSTA, KCI-Korean Journal Database, Russian Science Citation Index, SciELO Citation Index, and Zoological

[1]The Cambridge Dictionary Online. Available online at: https://dictionary.cambridge.org/us/dictionary/english/nature

Record) (1864—present), PsychInfo (1597—present), ProQuest Dissertations and Theses (1861—present), and PubMed (1966—present). Searches were re-run on May 18, 2017 to capture fresh publications.

Searches in Web of Science and PsychInfo used search terms including synonyms of nature, exposure, time elements, university students and terms relative to mental health and wellness (see **Appendix A** for complete search details). ProQuest Dissertations and Theses, a bibliographic database that has limited search capabilities, was searched with: *su((“health”) AND “nature”).* PubMed, a bibliographic database that indexes some literature relevant to this review, was searched using the following string: *(health[MeSH Terms]) AND nature[MeSH Terms].* Preliminary attempts to build a search in PubMed using text words ([tw]) or title and abstract words ([tiab]) to capture entries not yet indexed by MeSH Terms yielded tens of thousands of entries that were outside the scope of this review, rendering the search result set too cumbersome to screen. Therefore, we only used MeSH searching in PubMed.

Additionally, the website Green Cities:Good Health (http://depts.washington.edu/hhwb/) was searched; experts in the field were contacted directly for updates on relevant research; and additional resources were identified via careful scrutiny of bibliographies of included literature.

Study Selection, Data Extraction

Studies were eligible for inclusion in this scoping review if they met the following criteria: (1) subjects were of average college age (no younger than 15, no older than 30); (2) the study examined a treatment of time (hours or minutes) in nature (excluding exposure to nature in urban microenvironments, e.g., looking at nature through a window or on a screen); (3) a change, if any, in mental health status was noted; (4) studies compared participants across at least two environments; and (5) the study was published in English or French. Studies that did not meet these criteria were excluded, as were studies that tracked change in mental health status based on days and weeks immersed in nature (e.g., Outward Bound-type activities) because this is not generally accessible to all students; studies that looked at exercise in nature, because physical activity could be a confounder; studies that were more than 20 years old; and studies that compared time outdoors to time indoors.

All identified resources were managed in Rayyan (https://rayyan.qcri.org/welcome). After removing duplicate records, all titles and abstracts were screened for relevence (inclusion criteria) by at least two reviewers, a third being used as a tie-breaker if needed. For resources not excluded based on titles and abstracts, full manuscripts were reviewed by at least two reviewers. For each included study, study characteristics, sample characteristics, and results were extracted to thematic tables in Microsoft Word and Microsoft Excel.

Data Analysis

Given that the subject matter of this scoping review extends into disciplines that rely on qualitative as well as quantitative research, and because many of the included studies relied on subjective measures and small sample sizes, this scoping review used a thematic analysis to look across studies and pull out themes for future consideration.

RESULTS

Included Studies and Characteristics

In sum, 11,799 resources were identified and once de-duplicated, 10,917 titles and abstracts were screened for relevance and inclusion; these included both gray and white literatures. Rayyan (https://rayyan.qcri.org/welcome) was used with the blind function turned on to reduce bias during screening. Some 10,762 resources were excluded for not meeting inclusion criteria based on a review of titles and abstracts. A total of 155 papers were considered via full-text review, and of those, 14 papers were included for review (**Figure 1**). All included papers were from peer-reviewed journals. From these included papers, data were extracted and collected to define participant age, type of exposure to nature, type of activity in nature, types of data collected, measures used, and resulting change in mental health status. This information is summarized in **Table 1**.

All included papers summarized studies that were implemented and published since 2000 and included people of college age; 13 of the 14 papers noted that the participants were college students. The studies had a minimum of 12 participants under investigation; four studies had 12 participants, and two studies had more than 100 participants (112 and 280 participants). A majority of studies ($n = 10$) had only male subjects; these studies were all conducted in Japan, and represent 449 people measured. The remainder of the studies had both males and females included, with more females studied than men overall (158 females, 96 males, 3 gender not reported). Two-thirds of the studies ($n = 10$) took place in Japan, led by a seemingly related study group (Park, Song, Lee, and Tsunetsugu). One study took place in Sweden, and the remaining studies took place in the United States ($n = 3$). All study sites, both natural and urban, appeared to be within short walking or driving distances from the subjects’ campuses, and would therefore be accessible to most students.

Synthesized Findings

As detailed in **Table 1**, all 14 studies compared participants’ measured physiological and affective responses following activities undertaken across two environments: a natural setting vs. an urbanized setting. The “nature” environments used in the studies were diverse, including college natural areas ($n = 1$; study #5), forests ($n = 4$; studies #4, 7–9), nature reserves or nature areas ($n = 4$; studies #1, 2, 6, 14), and urban parks ($n = 5$; studies #3, 10–13). The “urban” environments used for comparison ($n = 14$) were all more built up, described as urban environment, city, or urban street view. The 14 studies ranged in the type of activity with which subjects were engaged in nature, including sitting ($n = 8$; studies #4–9, 13–14), walking ($n = 10$; studies #1–3, 6–7, 9–13), and walking quickly ($n = 1$; study #3) (counts not mutually exclusive).

Also as summarized in **Table 1**, and detailed in **Tables 3–5**, the “dose” of nature evaluated in the 14 studies ranged from 10 to 50 min. Ten studies (studies #4–12, 14) looked at a time dose of

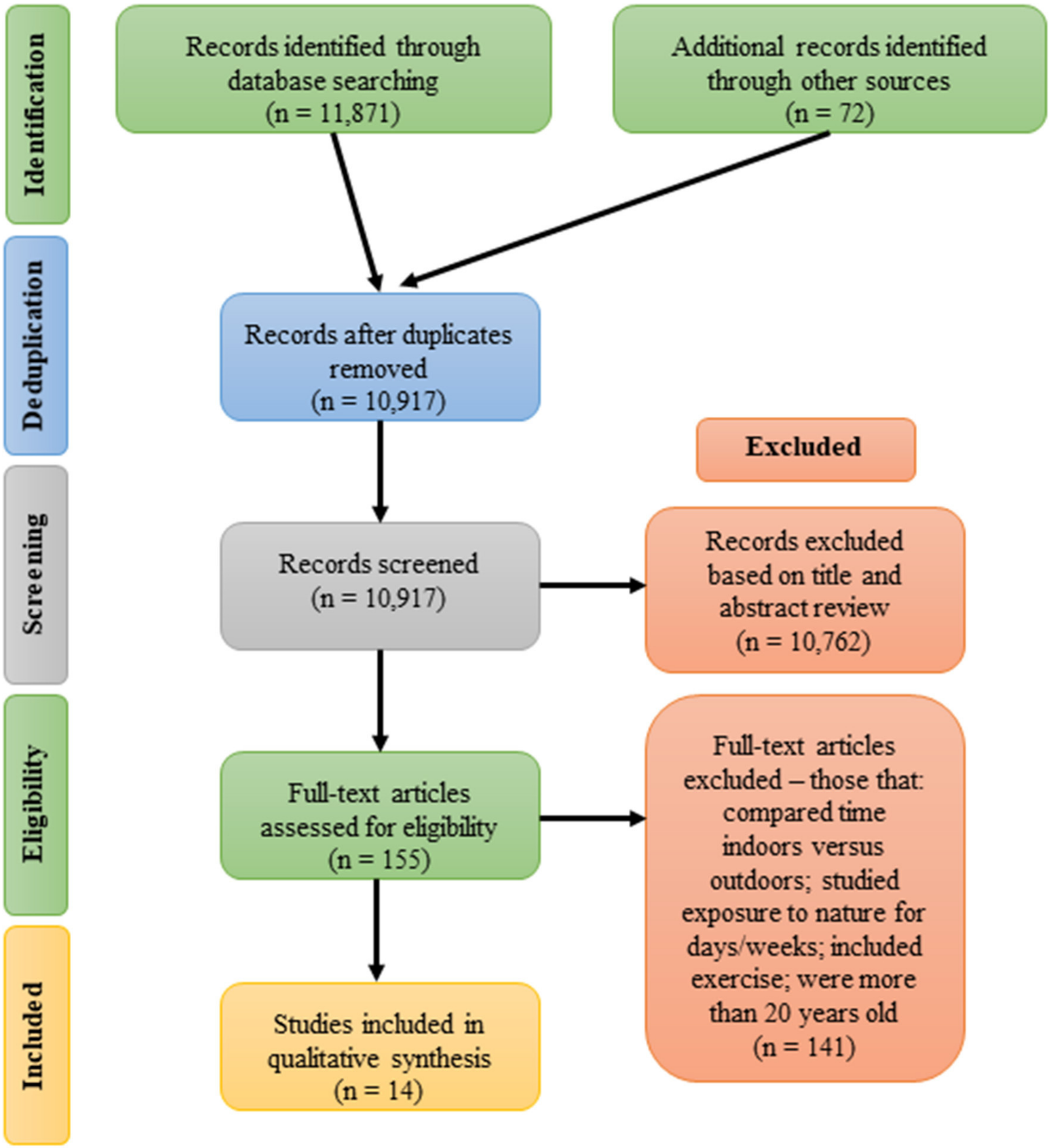

FIGURE 1 | PRISMA flow diagram.

10 to 21 min, and three studies (studies #1–3) looked at a time dose of 50 min. One study (study #13) considered a 30-min dose. In all cases, effect of time in nature was measured after one event or one dose.

All but one study (study #6) utilized a within-subject cross-over design whereby all participants were studied under two conditions to help rule out confounders based on sample distribution.

A total of 22 different measures were employed in the 14 studies to assess changes in participants' physiology and affect following time in nature. These assessment methods, described in **Table 2**, can largely be grouped into three categories.

(1) *Physiology*. A person's body reacts to stress, and physiological monitoring and tests can be used to assess changes in a person's body via known markers, including heart rate, heart rate variability, blood pressure, and salivary cortisol levels. A full 93% ($n = 13$) of the studies (all but study #1) included in this review used measures to assess the participants' physiological changes due to time in nature.

TABLE 1 | Characteristics of included studies.

Study	Type of study	Sample	Location	Dose	Activity	Type of Nature	Measures
#1 Berman et al. (2008)	Within-subject crossover: natural vs. urban	38 College age Mean 22.3 years 61% female	U.S.A. Michigan	50-min, once	Walk	Secluded, tree-lined arboretum vs. urban walk on heavily-trafficked street	Affect (PANAS) Attention (backwards digit-span task)
#2 Hartig et al. (2003)	Within-subject crossover: natural vs. urban	112 College age Mean 20.8 years 50% female	U.S.A. California	50-min, once	Slow-pace walk ("saunter")	Nature reserve with dirt road vs. urban city with sidewalks	Physiology (blood pressure) Affect (ZIPERS) (OHS) Attention (NCPCT) (memory—Smith and Miles)
#3 Johansson et al. (2011)	Within subject crossover: natural vs. urban	20 College age Age 20–29 50% female	Sweden	50-min, once	Brisk walk	Landscaped park with no roads or large buildings vs. urban walk on sidewalks adjacent to trafficked road with many buildings	Affect (EFI scale) (NMS scale) (PSS) Attention (Symbol Substitution Test)
#4 Lee et al. (2009)	Within-subject crossover: natural vs. urban	12 College students Mean 21.3 years Male	Japan	15-min, once	Sit and view	Dense forest vs. urban commercial street with traffic and dense buildings	Physiology (cortisol) (blood pressure) (heart rate) Affect (self-report)
#5 Lee et al. (2011)	Within-subject crossover: natural vs. urban	20 College students Mean 21.2 years Male	Japan	15 min, once	Sit and view	Natural area on campus with trees and pond vs. urban commercial area	Physiology (heart rate) (heart rate variability) (cortisol) Affect (SD) (POMS) (STAI) (SCL-90-R)
#6 Mayer et al. (2009)	Study #1 Urban walk, nature preserve. Not crossover	76 College age No age (intro class) 66% female	USA	10 + 5 min, once	Walk Sit	Natural setting walk vs. urban walk	Physiology (PANAS) Affect (self-awareness)
#7 Park et al. (2007)	Within-subject crossover: natural vs. urban	12 College students Mean 22.8 years Male	Japan	20 min, each	Walk + Sit	Forest area vs. urban commercial area	Physiology (neural activity) (cortisol) Affect (comfort) (calm)
#8 Park et al. (2008)	Within-subject crossover: natural vs. urban	12 College students Mean 21.3 years Male	Japan	15 min, once	Sit and view	Dense forest view vs. urban street view (dense, traffic)	Physiology (cortisol) (heart rate) (heart rate variability) Affect (self-report) (relaxation)
#9 Park et al. (2010)	Summary of 24 within-subject crossover: natural vs. urban	280 College students Mean 21.7 years Male	Japan	11–21 min, 12–16 min sit, once	Walk + Sit	Forest walk + sit vs. urban walk + sit	Physiology (cortisol) (heart rate) (blood pressure) (sympathetic nerve activity) Affect (POMS)
#10 Song et al. (2013)	Within-subject crossover: natural vs. urban	13 College age Mean 22.5 years Male	Japan	15 min, once	Walk	Urban park vs. city area	Physiology (heart rate) (heart rate variability) Affect (SD) (POMS) (STAI)
#11 Song et al. (2014)	Within-subject crossover: urban park vs. urban	17 College age Mean 21.2 years Male	Japan	15 min, once	Walk	Urban park with trees and flowers vs. city area	Physiology (heart rate) (heart rate variability) Affect (SD) (POMS) (STAI)
#12 Song et al. (2015)	Within-subject crossover: urban park vs. urban streets	23 College age Mean 22.3 years Male	Japan	15 min, once	Walk	Urban park walk (trees, pond) vs. urban street walk (residential area)	Physiology (heart rate) (heart rate variability) Affect (SD) (POMS) (STAI) (relaxation)
#13 Tsunetsugu et al. (2007)	Within-subject crossover: natural vs. urban	12 College students Mean 22.0 years Male	Japan	15 min+ 15 min, once	Walk Sit and view	Urban park walk (trees, pond) vs. urban street walk (residential area)	Physiology (blood pressure) (cortisol) (heart rate) (heart rate variability) (immunoglobulin A) Affect (self-report)
#14 Tsunetsugu et al. (2013)	Summary of 4 within-subject crossover: natural vs. urban	48 College age Mean 21.1 years Male	Japan	15 min, once	Sit and view	Natural setting (no street or buildings in view) vs. urban street view (dense, traffic)	Physiology (blood pressure) (heart rate) (heart rate variability) Affect (POMS) (self-report) (refreshed)

(2) *Affect*. Psychometric tests of affect, mood, and volition have been used for many years to assess people's disposition. All 14 of the studies included in this review used at least one measure of affect to assess the participants' psychological changes due to time in nature. As detailed in **Table 2**, this included 17 different assessments, 12

TABLE 2 | Description of measures used in included studies.

Type of test	Test + meaning of test result
Physiology (American Psychological Association, 2019b)	Sympathetic Nerve Activity • Under stress, the "fight or flight" response is activated in the body by the sympathetic nervous system (SNS). The SNS acts to release cortisol into the blood. SNS activity can be measured by heart rate variability, via the R-R interval (time duration between two consecutive R waves as measured on an electrocardiogram) (Park et al., 2008). High frequency elements act as a marker of parasympathetic activity (calm); a formula using low and high frequency elements acts as a marker of sympathetic activity (stress) (Lee et al., 2011). Salivary Cortisol Levels • Cortisol is a naturally-occurring hormone that is released under stress. When cortisol increases, the body responds by increasing heart rate, blood pressure, muscle tension, and respiratory rate. Levels of cortisol can be measured via mouth, with a swab or pipette that absorbs saliva. Heart Rate • Heart rate spikes when cortisol levels increase (under stress), and can be measured manually or remotely via monitors. Blood Pressure • Blood pressure spikes when cortisol levels increase (under stress) as blood vessels dilate to get more blood to the body; this is measured via a cuff. Secretory Immunoglobulin A • A marker of stress, as measured via saliva (Fan et al., 2008; Benham et al., 2009).
Affect	EFI: Exercise-Induced Feeling Inventory (Gauvin and Rejeski, 1993) • Self-report questionnaire to assess positive and negative affect • 12 questions to assess current feelings (calm, energetic, enthusiastic, fatigued, happy, peaceful, refreshed, relaxed, revived, tired, upbeat, worn out) • All items scored on a 5-point Likert scale ("do not feel" to "feel very strongly") NMS: Negative Mood Scale (Scott et al., 2001) • A measure of immediate and/or persistence affective responses • 19 items measured (e.g., worried, anxious, sad, angry, irritable, rushed) • All items scored on a 5-point scale ("not at all" to "very much") OHS: Overall Happiness Scale (Campbell et al., 1976) • A measure of quality of life • All items scores on a 100-point thermometer-like graph ("very unhappy" to "very happy") PANAS: The Positive and Negative Affect Schedule (Watson et al., 1988; Crawford and Henry, 2010) • Validated self-report questionnaire to assess positive and negative affect • Mostly used in research settings • 10 questions for positive affect (active, alert, attentive, determined, excited, enthusiastic, inspired, interested, proud, strong); 10 for negative affect (afraid, ashamed, distressed, guilty, hostile, irritable, jittery, nervous, scared, upset). • All items scored on a 5-point Likert scale ("not at all" to "extremely") POMS: Profile of Mood States (Heuchert and McNair) • Validated self-report questionnaire to assess mood disturbance • Measures seven dimensions of fluctuating feelings and affect states [anger-hostility (AH), confusion-bewilderment (C), depression-dejection (D), fatigue-inertia (F), tension-anxiety (TA), vigor-activity (V)] • Long form has 65 questions; short form has 35 questions • All items scored on a 5-point Likert scale ("not at all" to "extremely") PSS: Perceived Stress Scale (Cohen, 1994) • Validated self-report questionnaire to assess perceived stress • 10 items that measure feeling for stress over the last month (using descriptors such as unpredictable, uncontrollable, and overloaded) • All items scored on a 5-point scale ("never" to "very often"); higher score indicates higher perceived stress Refreshed (Mackay et al., 1978) • (It appears that this measure might come from Mackay's scale that was published in 1978. The scale uses 30 adjectives to allow a respondent to sell assess stress and arousal. It is unclear if the full scale was used, or just questions that relate to feelings of being refreshed.) SD: Semantic Differential (Summers, 1970) • Pairs of adjectives presented (i.e., comfortable–uncomfortable, soothed—aroused, natural–artificial) • Respondents plot their "position" on a scale between the two adjectives; 3-, 5-, or 7-point scale can be used SCL-90-R: Symptom Checklist-90-Revised (Derogatis, 1994) • Validated self-report tool that evaluates a range of psychological problems and symptoms of psychopathology • Can be used in research or in clinical setting; good for measuring change in symptoms, including depression and anxiety • 90 questions in 9 symptom dimensions (anxiety, depression, hostility, interpersonal sensitivity, obsessive-compulsive, paranoid ideation, phobic anxiety, psychoticism, somatization scored on a 5-point scale STAI: The State-Trait Anxiety Inventory (American Psychological Association, 2019a) • Measure of trait and state anxiety • Can be used in research (measure of distress) or in clinical setting (diagnose anxiety) • 20 items measured for trait anxiety (e.g., tension, worry, calm, secure); 20 items measured for state anxiety (e.g., worried too much, content, steady person) • All items scored on a 4-point scale ("almost never" to "almost always") • Higher score means higher anxiety

(Continued)

TABLE 2 | Continued

Type of test	Test + meaning of test result
	ZIPERS: Zuckerman Inventory of Personal Reactions (Zuckerman, 1977) • Validated self-report questionnaire to assess feelings and reactions • 12 measures in five domains (attentiveness, anger/aggression, fear, positive affect, sadness). • All items scored on a 5-point scale ("not at all" to "very much") • A sensitive measure in previous experimental research on the relative restorative potentials of natural and urban environments RRQ: Reflection Rumination Questionnaire (Trapnell and Campbell, 1999) • Two scales that measure rumination and reflection • 12 items measured for rumination (e.g., "My attention is often focused on aspects of myself I wish I'd stop thinking about") • All items scored on a 5-point scale ("strongly disagree" to "strongly agree") • Higher means of the sum of scores indicate higher degrees of rumination. Self-Reports: (non-validated measures) • Comfort, Calm, Positive Feeling, Relaxation, Self-awareness
Attention	NCPCT: Necker Cube Pattern Control Test (De Young, 2016; Zealand) • Test of capacity to direct mental effort, the ability to inhibit one response over another. When placed under prolonged demand, the ability to direct mental focus diminishes; this decreases mental effectiveness. • Participants view a sketch of a 3-D cube, and note (press the spacebar) when they see one orientation vs. the other. After a baseline measure, participants try to control seeing one perspective vs. another, and note when the orientation shifts. A lower score (over 30 s) shows greater attention. Backwards Digit-Span Task (Berman et al., 2008) • Participants hear sequences of digits and are asked to repeat them in reverse order. • Sequences can vary in length (three to nine digits were used in noted study) • Correct sequences were scored the same, independent of sequence length • The backwards digit-span task depends on directed-attention abilities because participants must move items in and out of their attentional focus which is a major component of short-term memory. SST: Symbol Substitution Test (Johansson et al., 2011) • A symbol substitution test requires sustained directed attention. • A subject writes numbers into a series of blanks, each of which is paired with one of nine symbols. The appropriate number for a symbol is indicated by a key. • After a practice trial, the subject is given 60 s to fill in as many of the 110 available blanks as possible. The score is the number of correctly assigned numbers. Memory-Loaded Search Task (Hartig et al., 2003) • A test of attention • Subjects search lines of letters for five target letters given at the beginning of each line. • Subjects memorize the five given targets, and then search through one line of text, once, to find the targets. • Over a 10-min period, subjects are encouraged to go quickly, but to be accurate. • Task is scored on accuracy: percent of target letters identified, and on speed: number of letters identified. Accuracy × Speed gives final score.

standardized and validated assessments (the Exercise-induced Feeling Inventory (EFI; Gauvin and Rejeski, 1993); the Negative Mood Scale (NMS; Scott et al., 2001); the Overall Happiness Scale (OHS; Campbell et al., 1976); the Positive and Negative Affect Schedule (Watson et al., 1988; Crawford and Henry, 2010; PANAS); the Profile of Mood States (POMS; Heuchert and McNair, 2019); the Perceived Stress Scale (PSS; Cohen, 1994); the Refreshed Scale (Mackay et al., 1978); the Semantic Differential Scale (SD; Summers, 1970); the Symptom Checklist-90-Revised (SCL-90-R; Derogatis, 1994); the State-Trait Anxiety Inventory (STAI; American Psychological Association, 2019a); the Zuckerman Inventory of Personal Reactions (ZIPERS; Zuckerman, 1977); the Reflection Rumination Questionnaire (RRQ; Trapnell and Campbell, 1999) and five study-specific assessments.

(3) *Attention*. Three of the studies included in this review (studies #1–3) also used measures of attention to assess whether time in nature influenced participants' memory or ability to focus. Four different standardized tests were used, including: the Necker Cube[2] Pattern Control Test (NCPCT; De Young, 2016); the Backwards digit-span task (Berman et al., 2008); the Symbol Substitution Test (SST; Johansson et al., 2011); and the Memory-Loaded Search Task (Hartig et al., 2003).

Across all of the studies included in the review, it appears that time in nature does have a positive effect on physiology, affect, and attention (**Tables 3–5**). In sum, as presented in **Figure 2** it appears that:

- *10–30 min of sitting outdoors* looking at or being in nature (**Table 3**) has the effect of decreasing biological and self-perceived markers of stress. When compared to those seated in an urban environment with a street view, often with traffic, those seated with a natural view (a campus green, a dense forest) showed stress reduction via **physiological measures:** significant decrease in heart rate (5 studies: #4, 5, 8, 9,

[2]The Necker Cube Test. Available online at: http://new.censusatschool.org.nz/wp-content/uploads/2013/09/NECKER-CUBE-FINAL.docx

TABLE 3 | Measured effects of time in nature via included studies 10–30 min of sitting outdoors: natural vs. urban view.

Dose	Study	Measured effect (from natural setting when compared to *urban setting*)
15-min Dense forest view vs. *Urban street view*	#4 (Lee et al., 2009)	When compared to those sitting in the urban setting, those sitting in the forest showed: Physiology (cortisol, blood pressure, heart rate) - Lower cortisol levels before and after viewing ($p < 0.01$) - Lower diastolic blood pressure after viewing ($p < 0.05$) - Lower heart rate after viewing ($p < 0.05$) Positive feelings (self-report) - Higher measures for feelings of comfort after viewing ($p < 0;01$) and in the evening ($p < 0.05$) - Higher restorative effects after viewing ($p < 0.01$) - Higher feelings of refreshment after viewing ($p < 0.05$) and in the evening ($p < 0.01$)
15 min Campus park view vs. *Urban view*	#5 (Lee et al., 2011)	When compared to those sitting in the urban setting, those sitting in the forest showed: Physiology (heart rate, heart rate variability, cortisol) - A decrease in heart rate ($p < 0.01$) - An increase in parasympathetic HR variability ($p < 0.01$) - Lower cortisol levels after viewing. Psychological (SD) (POMS) (STAI) (SCL-90-R) - Higher values for three adjective pairs: comfortable-uncomfortable, soothed-aroused, and natural-artificial ($p < 0.01$) (SD) - Decreased measures for somatization, obsessive-compulsive, interpersonal-sensitivity, depression, anxiety, hostility, and paranoid ideation ($p < 0.01$) (SCL-90-R) - Lower levels of negative feelings: tension-anxiety, depression, anger-hostility, fatigue, and confusion ($p < 0.01$) (POMS) - Higher levels of vigor ($p < 0.01$) (POMS) - Decreased state of anxiety ($p < 0.01$) (STAI)
15 min Dense forest view vs. *Urban street view*	#8 (Park et al., 2008)	When compared to those sitting in the urban setting, those sitting in the forest showed: Physiology (cortisol, heart rate, heart rate variability) - Lower heart rate before and after viewing ($p < 0.01$) - Higher parasympathetic HR variability while viewing ($p < 0.05$) - Lower cortisol levels before viewing ($p < 0.05$), after viewing ($p < .05$), and the evening ($p < 0.06$) Positive feelings (self-reported) - Higher feelings of comfortability after viewing ($p < 0.01$) and in the evening ($p < 0.05$) - Higher feelings of calmness after viewing ($p < 0.01$) Self-perception - Higher refreshed feelings after viewing and in the evening ($p < 0.05$)
11–21 min Forest sit vs. *Urban sit*	#9 (Park et al., 2010)	When compared to those sitting in the urban setting, those sitting in the forest showed: Physiology (cortisol, heart rate, blood pressure, sympathetic nerve activity) - Lower cortisol levels ($p < 0.01$) - Lower heart rate ($p < 0.01$) - Lower systolic blood pressure ($p < 0.01$) - Lower diastolic blood pressure ($p < 0.05$) - Higher parasympathetic HR variability ($p < 0.01$) - Lower sympathetic HR variability ($p < 0.01$) Psychological (POMS) - A decrease in negative POMS subscales (Tension/Anxiety, Depression, Anger/Hostility, Fatigue, Confusion) ($p < 0.01$, $p < 0.05$) - An increase in the positive POMS subscale, Vigor ($p < 0.01$)
15 min Natural view vs. *Urban street view*	#14 (Tsunetsugu et al., 2013)	When compared to those sitting in the urban setting, those sitting in the forest showed: Physiology (blood pressure, heart rate) - Lower diastolic blood pressure ($p < 0.05$) - Higher parasympathetic HR variability ($p < 0.01$) - Suppression of sympathetic nervous activity (LF/HR ratio, $p < 0.05$) - Lower heart rate ($p < 0.01$) Psychological (POMS) - Lower Tension-Anxiety score ($p < 0.01$) - Lower Fatigue score ($p < 0.01$) - Lower Confusion score ($p < 0.01$) - Higher Vigor score ($p < 0.01$) Positive feelings (self-report) (refreshed Mackay et al., 1978) - Higher comfortability feelings ($p = 0.00$, $r = 0.51$) - Higher soothing feelings ($p = 0.00$, $r = 0.53$) - Higher natural feelings($p = 0.00$, $r = 0.59$) - Higher refreshment feelings ($p = 0.00$, $r = 0.55$)

TABLE 4 | Measured effects of time in nature via included studies 10–30 min of walking outdoors: natural vs. urban setting.

Dose	Study	Measured effect (from natural setting when compared to *urban setting*)
10 + 5 min Natural walk vs. *Urban walk*	#6 (Mayer et al., 2009)	When compared to those walking in the city, those walking in a natural area showed: Physiology (central nervous system) - A greater increase in CNS ($p < 0.05$) Psychological (PANAS) - A greater increase PANAS scores ($p < 0.05$)
20 min Forest area walk vs. *Urban walk*	#7 (Park et al., 2007)	When compared to those walking in the city, those walking in a forest area showed: Physiology (neural activity, cortisol) - A greater decrease in neural activity ($p < 0.01$) - A greater decrease in cortisol levels ($p < 0.01$) Self-perception (comfort, calm) - A greater increase in levels of calm ($p < 0.01$) - A greater increase in levels of comfort ($p < 0.01$)
11–21 min Forest walk vs. *Urban walk*	#9 (Park et al., 2010)	When compared to those walking in an urban environment, those walking in the forest showed: Physiology (cortisol, heart rate, blood pressure, sympathetic nerve activity) - Lower cortisol levels ($p < 0.01$) - Lower heart rate ($p < 0.01$) - Lower systolic blood pressure ($p < 0.05$) - Lower diastolic blood pressure ($p < 0.05$) - Higher parasympathetic HR variability ($p < 0.05$) - Lower sympathetic HR variability ($p < 0.05$) Psychological (POMS) - A decrease in negative POMS subscales (Tension/Anxiety, Depression, Anger/Hostility, Fatigue, Confusion) ($p < 0.01$, $p < 0.05$) - An increase in the positive POMS subscale, Vigor ($p < 0.01$)
15 min Urban park walk vs. *City area walk*	#10 (Song et al., 2013)	When compared to those walking in the city, those walking in the urban park showed: Physiology (heart rate, heart rate variability) - A greater decrease HR ($p < 0.05$) - A greater increase parasympathetic HR variability ($p < 0.01$) - A greater decrease sympathetic HR variability ($p = 0.06$) Psychological (SD) (POMS) (STAI) - A greater increase in SD score ($p < 0.01$) - A greater decrease in negative POMS scores and an increase in positive POMS scores ($p < 0.01$) - A greater decrease in STAI scores ($p < 0.05$)
15 min Urban park walk vs. *City street walk*	#11 (Song et al., 2014)	When compared to those walking in the city, those walking in the urban park showed: Physiology (heart rate, heart rate variability) - A greater decrease in HR ($p < 0.05$) - A greater increase in parasympathetic HR variability ($p < 0.01$) - A greater decrease in sympathetic HR variability ($p < 0.01$) Psychological (SD) (POMS) (STAI) - A greater decrease in STAI scores ($p < 0.05$) - A greater decrease in negative POMS scores, an increase in positive POMS scores ($p < 0.05$) - A greater increase in SD scores ($p < 0.05$)
15 min Urban park walk vs. *Urban street walk*	#12 (Song et al., 2015)	When compared to those walking in the city, those walking in the urban park showed: Physiology (heart rate, heart rate variability) - A greater decrease HR ($p < 0.01$) - A greater increase parasympathetic HR variability ($p < 0.01$) - A greater decrease sympathetic HR variability ($p < 0.01$) Psychological (POMS) (STAI) (SD) - A greater increase in SD score ($p < 0.01$) - A greater decrease in negative POMS scores and an increase in positive POMS scores ($p < 0.05$) - A greater decrease in STAI scores ($p < 0.01$)
15 +15 min Urban park walk vs. *Urban street walk*	#13 (Tsunetsugu et al., 2007)	When compared to those walking in the city, those walking in the urban park showed: Physiology (blood pressure, cortisol, heart rate, heart rate variability, immunoglobulin A) - A greater decrease in cortisol ($p < 0.05$) - A greater decrease in HR ($p < 0.05$) - A greater decrease in blood pressure ($p < 0.05$) - A greater increase in parasympathetic HR variability ($p < 0.05$) - A greater decrease in sympathetic HR variability ($p < 0.05$) Positive feelings (self-report) - An increase in feelings of "calm, comfortable, refreshed" ($p < 0.05$)

TABLE 5 | Measured effects of time in nature via included studies 31–60 min of walking outdoors: natural vs. urban setting.

Dose	Study	Measured effect (from natural setting when compared to *urban setting*)
50-min Arboretum walk vs. *Urban walk*	#1 (Berman et al., 2008)	When compared to those walking in the city, those walking in the natural setting showed: Mood (PANAS—positive subscales) - No significant difference measured between groups Attention - A greater increase of 1.5 digits on backwards digit-span task (t(36) = 4.783, prep = 0.99)
50-min Nature reserve walk vs. *Urban city walk*	#2 (Hartig et al., 2003)	When compared to those walking in the city, those walking in the natural setting showed: Physiology (blood pressure) - A greater decrease in blood pressure, 30 minutes into walk ($p < 0.01$). Significance lost at the end of the trial. Emotion (ZIPERS)(OHS) - A greater increase in positive emotion, and a greater decrease in feelings of anger and aggressiveness ($p < 0.01$) (ZIPERS) - No significant difference measured in overall happiness (OHS) Attention (NCPCT) - No significant change in attention could be measured.
50-min Park walk vs. *Urban walk*	#3 (Johansson et al., 2011)	When compared to those walking in the city alone and with a friend, those in the natural setting showed: Affect (EFI scale) (NMS scale) - An increase in revitalization while walking alone and while walking with a friend. The greatest effect was observed while walking alone ($p < 0.05$) (EFI) - A decrease in feelings of being rushed while walking alone ($p < 0.05$) (NMS) Attention (Symbol Substitution Test) - A decline in attention score results ($p < 0.05$) <Result was unexpected> Perceived Stress (PSS) - No significant difference was noticed in PSS.

14), significant decrease in cortisol levels (3 studies: #4, 8, 9; a fourth study (#5) showed a non-significant decrease), significant decrease in blood pressure (3 studies: #4, 9, 14), significant increase in parasympathetic nervous system activity, and a significant decrease in sympathetic nervous system activity (4 studies: #5, 8, 9, 14, measured via heart rate variability); and via **psychological measures:** significant decrease in negative POMS scores and significant increase in positive POMS scores (3 studies: #5, 9, 14), significant decrease in STAI scores (1 study: #5), significant increase in SD scores (1 study: #5), significant decrease in SCL-90-R scores (1 study: #5), and significant increase in self-reported feelings of calm, comfort, being refreshed, and restored (3 studies: #4, 8, 14).

- *10–30 min of walking outdoors* in nature (**Table 4**) has the effect of decreasing markers of stress. When compared to those walking in an urban environment on concrete sidewalks alongside traffic, those walking in nature showed stress reduction via **physiological measures:** significant decrease in heart rate (5 studies: #9–13), significant decrease in cortisol levels (3 studies: #7, 9, 13), significant decrease in blood pressure (2 studies: #9, 13), significant increase in parasympathetic nervous system activity and a significant decrease in sympathetic nervous system activity (5 studies: #9–13, measured via heart rate variability), and a significant difference in neural/central nervous system activity (2 studies: #6, 7); and via **psychological measures:** significant decrease in negative POMS scores and significant increase in positive POMS scores (4 studies: #9–12), significant decrease in STAI scores (3 studies: #10–12), significant increase in SD scores (3 studies: #10–12), significant increase in PANAS scores (1 study: #6), and significant increase in self-reported feelings of calm, comfort, and refreshed (2 studies: #7, 13).
- *31–50 min of walking outdoors* in nature (**Table 5**) has the effect of decreasing markers of stress. When compared to those walking in an urban environment, on concrete sidewalks alongside traffic, those walking in nature showed stress reduction via **physiological measures:** significant decrease in blood pressure 30 min into a walk, although no difference at end (1 study: #2); and via **psychological measures:** significant increase in positive emotion ZIPERS scores and significant decrease in negative emotion ZIPERS scores (1 study: #2), significant increase in revitalization (EFI score, 1 study: #3), and significant decrease in feeling rushed (NMS score, 1 study: #3). There was no significant difference measured in perceived stress (PSS score, 1 study: #3), in overall happiness (OHS score, 1 study: #2), or in the positive subscales of the PANAS (1 study: #1). Those walking in nature also showed varying differences in **attention:** no significant difference via the NCPCT scale (1 study: #2), an increase in attention via the backwards digit-span task, and a significant decrease in attention via the SST.

DISCUSSION

Summary of Main Findings

The goals of this scoping review were to comprehensively scan the available literature to (1) identify what *accessible and sustainable dose of time in nature* appears to elicit a positive impact on *mental health* in people of college-age, (2) describe what types of engagement with nature (i.e., passive vs. active engagement) provide said impacts, (3) describe the most commonly used measures of effect, and (4) identify the strengths

	≈ 15 minutes in nature				≈ 50 minutes in nature			
	Park		Woods/Forest		Park		Woods/Forest	
Sitting	Song 2013 (#10)	□■ ○○●	Mayer 2009 (#6)	■ ●	Johansson 2011 (#3)	●● Δ	Berman 2008 (#1)	
Sitting	Song 2014 (#11)	□□■ ●●●	Park 2007 (#7)	□□ ○○			Hartig 2003 (#2)	□ ○
Sitting	Song 2015 (#12)	□□□ ○○●	Park 2010 (#9)	□□■■■■ ○○●				
Sitting	Tsunetsugu 2007 (#13)	■■■■■ ●						
Walking	Lee 2011 (#5)	□□ ○○○○○	Lee 2009 (#4)	□■■ ○○○●●				
Walking			Park 2008 (#8)	□■■■■ ○○●●				
Walking			Park 2010 (#9)	□□□□□■ ○○●				
Walking			Tsunetsugu 2013 (#14)	□□■■ ○○○○				

Measured positive effect, when compared to similar experience in non-nature setting:

Physiological Measures (Table 2) and Effect (Tables 3, 4, 5):	□ ($p<0.01$)	■ ($p<0.05$)
Measures of Affect (Table 2) and Effect (Tables 3, 4, 5):	○ ($p<0.01$)	● ($p<0.05$)
Measured of Attention (Table 2) and Effect (Tables 3, 4, 5):	Δ ($p<0.05$)	

FIGURE 2 | Reported effects or benefits of time in nature, as compared to similar experience in non-nature setting (summary of data from **Tables 3**–**5**).

and gaps in the literature (methods and understanding) to guide future research. Strict search limits were used to screen more than 10,000 documents, ultimately identifying only 14 peer-reviewed manuscripts that met the scoping review inclusion criteria, where study subjects were of average college age (15–30 years old); where time in nature was explicitly measured in hours or minutes and limited to time that would be accessible to all college students in a sustainable, long-term way; and where the studies took place in an outdoor nature settings.

The 14 studies examined in this review revealed that as little as 10–20 min and up to 50 min of sitting or walking in a diverse array of natural settings has significant and positive impacts on key psychological and physiological markers, when contrasted with equal durations spent in urbanized settings.

To assess changes in the study participants' physiological and psychological markers of stress following time in nature, a total of 22 different measures were employed across the 14 studies, including biological measures of physiology, standardized and non-standardized measures of affect, and standardized and non-standardized measures of attention.

Within the included studies, statistically significant differences in physiological health markers of stress were associated with time in nature, including decreased heart rate, salivary cortisol, blood pressure, and sympathetic nervous system activity, and increased parasympathetic nervous system activity. Furthermore, within the included studies, statistically significant differences in psychological health markers of reduced stress were also attributed to time spent in nature, including decreased negative POMS scores (less anger-hostility, confusion-bewilderment, depression-dejection, fatigue-inertia, tension-anxiety); increased positive POMS scores (more vigor-activity): decreased STAI scores (lower anxiety); increased SD scores (greater sense of comfort, being soothed, feeling natural); increased PANAS scores (positive affect); and increased self-reported feelings of calm, comfort, and being refreshed.

The findings of this review are similar to studies of non-college-aged populations that have found evidence of stress reduction through engagement with nature (Fan et al., 2008; Benham et al., 2009; Hartig et al., 2014; Frumkin et al., 2017; Hansen et al., 2017; Antonelli et al., 2019; Hunter et al., 2019). On the strength of the papers included in this scoping review, there is no reason to doubt that these same stress-relieving benefits accrue to those of college age. This paper adds value to the literature in showing that a dose of as little as 10–20 min sitting or walking in an array of green spaces can have a meaningful impact in reducing stress, anger, anxiety, and in increasing vigor, comfort, positive affect, and a sense of feeling refreshed. Identifying and utilizing nature as an upstream easy, cost-effective tool to prevent and/or combat stress can help society alleviate a substantial health burden that contributes to and exacerbates myriad other negative physiological and psychological conditions (Maller et al., 2006).

Limitations

Limitations of this scoping review include inclusion, heterogeneity, confounders, bias, and possibly scope. As noted above, this review only includes studies that were published and available/identifiable, and met the inclusion criteria. Although, a systematic and multi-pronged approach was used to identify eligible studies, it is possible that some were missed.

In reviewing across the 14 included studies, the researchers did note heterogeneity of study sites (countries and cities), meaning that findings may not be generalizable to all populations and locations. Three of the 14 studies were conducted in the United States, one in Sweden, and 10 in Japan. The Japanese studies were led by members of a seemingly related research team. Since the 1980s, the Japanese government has led a major initiative to connect its citizens with nature through "Shinrin-yoku," or "forest bathing," programs. Although there is no reason to doubt the rigor of these studies, a certain degree of scientific skepticism may be warranted. Finally, participant groups in more than half of the studies were male only, and it is unclear if the findings on male participants can be generalized to females in the same age group. Therefore, it would be appropriate to duplicate these studies in a multiplicity of locations, with equal cohorts of males and females.

This scoping review also summarized the noted benefits of time in nature, including physiological measures (such as heart rate, cortisol levels, and blood pressure), psychological measures (such as stress, happiness, calm, comfort, and restoration), and attention. While these are measures that prior research has shown to be affected by time in nature, these are also measures that may be affected by other confounding factors such as exercise (e.g., running, hiking). This scoping review does not take that into account. However, to limit confounding factors (knowing that exercise can impact these measures), and to support our goal of identifying accessible and sustainable doses of time in nature (activities that anyone could do, regardless of means), studies that included vigorous exercise, or explicitly focused on the effect of exercise in nature, were excluded in favor of studies that looked at accessible and routine activities, such as walking and sitting.

As a scoping review to inform future research or practice, risk of bias was not assessed within each of the included studies, as may be common in more formal systematic reviews. Of note, however, a recent systematic review led by Antonelli et al. (2019) did evaluate the quality of four studies included in this scoping review (Park et al., 2007, 2008, 2010; Tsunetsugu et al., 2007), rating them as as fair quality (NIH tool) and with high risk of bias (Cochrane tool). Related to this specific review, there may be bias in the summary of findings in that the authors have extracted these findings based on publications that were identified. Inherent bias may exist as it is possible that some studies on this topic were not published, especially those which may not have produced compelling or positive results. Although experts in the field were contacted to obtain the most up to date information, the authors acknowledge that not all relevant knowledge on this topic may have been captured.

Lastly, the purpose of this study was a scoping review, and as such, did not include a meta-analysis of results across studies. While a thematic analysis approach was used, based on within-study findings, interpretation and generalization of the results may be difficult due to the relatively small sample sizes for most included studies, and the variety of measures of effect used, including subjective measures.

Conclusions

Stress, depression, and anxiety are affecting college students in the U.S. at alarmingly high rates, and there is an urgent need to find modalities for helping this population cope by providing individuals agency to improve their own mental health and well-being. An increasing number of studies have provided evidence that people who spend time in nature-rich environments benefit psychologically and physiologically. Although the heterogeneity of methodologies makes conclusions difficult, this scoping review summarizes studies that show that as little as 10–20 min of time spent sitting or walking in nature has a beneficial effect on college-aged adults' mental health, and that the same amount of time spent outdoors in urbanized settings does not have the same benefits.

Institutions of higher learning, as well as healthcare organizations and other entities that interact regularly with this population, should strongly consider providing access to nature on their campuses. They should also provide programs that encourage people in this age group to take advantage of this valuable resource. Several colleges and universities have instituted "Nature Rx" or "Park Prescription" programs that employ dedicated websites, health clinic-offered nature prescriptions, and nature experience classes to encourage all students, regardless of their health status, to spend time exploring the natural world (Razani et al., 2018; Rakow and Eells, 2019).

Researchers have begun to discuss access to nature in a public health and epidemiology context rather than simply as an issue of environmental psychology and design (Kuo, 2015; Frumkin et al., 2017; Fong et al., 2018). As an ever larger body of scientific evidence regarding the beneficial effects of time spent in nature is amassed, one can imagine this research having an impact on national health policies. Much as current policies provide guidelines for healthy diet and exercise, future strategies may stipulate the minimum time an individual should spend in nature each day or week.

Based on the limited number of published studies on this topic and with this population, more primary and translational research, implemented in a consistent manner, is warranted. To this end, the research team suggests six specific foci:

1. More applied research in this population in the U.S., based on campus settings, to evaluate the feasibility and impact of various types of interventions. This could include highly-controlled research using a cross-over design (differences in effect based on time in exposure 1 vs. exposure 2), and applied research studies that document and measure the effects of specific intervention types (i.e., park prescription, NatureRx,

or course-based programs). In this area, papers on processes and outcomes—including successes and failures—would be of value.

2. More consistent use of similar measures and tools across studies to develop a larger pool of results that allow for meta-analyses. More focused adoption of a smaller number of measures and tools that could be readily used with larger numbers of study participants—with equal numbers of key demographics—could create a statistically stronger evidence base.
3. More collaboration across study sites to increase statistical power of studies, including larger sample sizes, consistency of measures, and consistency of similar activities across different regions and types of nature settings. Based on the studies summarized in this review, it appears that 10–20 min of time in nature has a positive effect on markers of mental health. Testing interventions, exposures (including frequency of repeated exposures), and benefits of college-age students across campuses and across seasons in the U.S. could provide some strong indications for public health interventions.
4. Deeper considerations for habitude or differences between groups, including those for whom time in nature is routine and the norm (vs. those who dislike nature), and those who live on a highly walkable campus (layout, climate, etc.) (vs. those who do not). Capturing data about routines and attitudes as pre-study may help control for varying measured effects.
5. Deeper considerations of the social aspects of nature experiences, and the complementary benefits that socialization brings. For example, is it more beneficial to engage in solitary or group nature-based experiences? Researchers might also measure the impact of different types of nature settings, such as, does a walk through an undisturbed woodland provide greater benefit than through a park-like setting?
6. Potential use of a public health approach for research, using big data, longitudinal analysis, and interactional analysis, such as the interaction between time spent in nature and other physical activity, or with body mass index. Successful research teams will include an interdisciplinary mix of scholars in design (architecture, landscape architecture, and planning), psychology, epidemiology, public health, pharmacology, and medicine.

AUTHOR CONTRIBUTIONS

GM, DR, and EE co-developed the concept of the paper. EE led the scoping review process. GM acted as the primary convener of the author group. GM, DR, and CM reviewed and adjudicated each identified paper and outlined the analysis. GM, CM, and SS conducted the analysis. DR, NS, and GM co-outlined the paper. DR, GM, EE, and NS co-wrote the paper. GM acted as the primary editor of the paper.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02942/full#supplementary-material

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Can Simulated Nature Support Mental Health? Comparing Short, Single-Doses of 360-Degree Nature Videos in Virtual Reality With the Outdoors

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Nature exposure in virtual reality (VR) can provide emotional well-being benefits for people who cannot access the outdoors. Little is known about how these simulated experiences compare with real outdoor experiences. We conduct an experiment with healthy undergraduate students that tests the effects of 6 min of outdoor nature exposure with 6 min of exposure to a 360-degree VR nature video, which is recorded at the outdoor nature exposure location. Skin conductivity, restorativeness, and mood before and after exposure are measured. We find that both types of nature exposure increase physiological arousal, benefit positive mood levels, and are restorative compared to an indoor setting without nature; however, for outdoor exposure, positive mood levels increase and for virtual nature, they stay the same. The nature-based experience shows benefits above and beyond the variance explained by participants' preferences, nature and VR experiences, and demographic characteristics. Settings where people have limited access to nature might consider using VR nature experiences to promote mental health.

Keywords: simulated nature, virtual reality, nature exposure, affect, skin conductance

INTRODUCTION

Not everyone has access to natural environments. This is a public health concern because nature promotes human health and wellbeing by mitigating adverse environmental stressors and providing salutogenic experiences (Depledge et al., 2011; Silva et al., 2018). Nearly two-thirds of Americans live in cities (Humes et al., 2011) and may have less access to safe green spaces than other citizens (Wolch et al., 2014; Rigolon et al., 2018a). Americans spend over a million days every two years in hospitals (Henry, 2016) where most windows look onto grayspace rather than greenspace (Trau et al., 2016). Over nine million adults in the United States and Europe live in assisted care facilities (Centers for Disease Control and Prevention, 2016) that have limited nearby nature

(Artmann et al., 2017). Approximately 40 million Americans are physically disabled and may struggle to go outdoors (Centers for Disease Control and Prevention, 2017). Even people with access to nature do not always feel comfortable going outside or have sufficient time to do so (Bixler and Floyd, 1999; Browning et al., 2017). These circumstances warrant the development of technologies that facilitate more frequent interactions with the natural world (Depledge et al., 2011).

One inexpensive and convenient way to provide access to nature is 360-degree videos in virtual reality (VR) (Depledge et al., 2011; Smith, 2015). VR has been defined as "inducing targeted behavior in an organism using artificial sensory stimulation, while the organism has little or no awareness of interference" (LaValle, 2017, pg. 1). In spring 2019, all-in-one VR headsets became commercially available for $399 USD or less. Widespread interest and research activity in VR technology, however, began much earlier. The Ultimate Display was demonstrated by Sutherland (1965) to track the head of a user and adjusted the simple graphics on a wearable display, thereby giving the illusion of a virtual environment that surrounds the user. Popular and commercial interest in VR soared in the 1980s and then diminished across the 1990s, mainly because the technology was too costly or ineffective due to hardware limitations. During that time, the cave automatic virtual environment (CAVE) was introduced, whereby users entered a room that had computer graphics projected onto surrounding walls (Cruz-Neira et al., 1992). The emergence of Oculus VR in 2012 caused a resurgence in popular interest because it delivered lower-cost VR headsets that leveraged the availability of smartphone hardware components, including inertial measurement unit (IMU) sensors and displays that tracked movement (Harris, 2019). In the fourth-quarter of 2018, all-in-one VR devices were announced, which required no additional components. Improvements continue to be made in lowering headset weight and cost, while improving display properties such as resolution and frame rate. Setup and computational demands for panoramic video viewing are lower than many targeted VR use cases. These recent advances make it easier for people to acquire and use this technology for therapeutic uses.

At least some of the benefits of nature exposure can be obtained through the visual and auditory exposure provided by all-in-one VR headsets. Attention restoration theory (Kaplan, 1995) and stress reduction theory (Ulrich, 1983) as well as the related scanning for threats theory (Browning and Alvarez, 2019) explain how visual exposure to natural landscapes capture people's fascination and match human evolutionary history or personal experiences and familiarity. Numerous studies now show that 360-degree nature videos are therapeutic (Maples-Keller et al., 2017; Jerdan et al., 2018; White et al., 2018) and improve mood within 6 (Schutte et al., 2017), 9 (Yu et al., 2018), or 15 min (Anderson et al., 2017). In addition to improvements in mood, cognitive functioning and physiological stress levels also show some benefit from brief 360-degree videos of nature (Gerber et al., 2017; Chung et al., 2018; Hedblom et al., 2019).

Nearly 200 studies have examined the human health and cognitive functioning benefits conferred by viewing still images, videos, and other simulations of nature (McMahan and Estes, 2015; Twohig-Bennett and Jones, 2018; White et al., 2018). Simulations have been defined as a "family of techniques utilized for replicating – or, more precisely, previewing or otherwise anticipating – in the laboratory everyday environments that have not yet been built, modified, or otherwise actualized" (Stokols, 1997, pg. 169). Simulations also include replications of fictional or existing environments shown in any location (not just the laboratory) that evoke a sense of presence: the psychological presence of "being there" (Witmer et al., 2005).

The literature is not clear on whether simulations of nature serve as substitutes for real nature experienced in the outdoors. On one hand, some participants have reported no difference in energy or stress after exposure to outdoor nature versus exposure to nature videos on TV (Kjellgren and Buhrkall, 2010). On the other hand, real views of nature seen from windows have reduced physiological markers of stress more than virtual views of nature seen from wall-mounted TVs (Kahn et al., 2008). VR may provide stronger beneficial effects of nature simulations than TV videos because of VR's high level of immersion. Immersion reflects the extent to which someone perceives themselves enveloped by, included in, and interacting with an environment (Witmer et al., 2005). Compared to less immersive technologies, VR simulations are more realistic (Hetherington et al., 1993), provide greater therapeutic benefits (de Kort et al., 2006), and elicit more feelings of awe that are central to attention restoration theory (Chirico et al., 2017).

At least three studies have compared the 360-degree nature videos with physical nature exposure, but their results are limited. One study's findings were confounded by the motion sickness felt by participants as they virtually walked through nature (Calogiuri et al., 2018). Another study took place indoors (Yin et al., 2018) and provided limited exposure to the full range of aromatic and auditory natural elements available outdoors (Silva et al., 2018). The third did not include a control group; as such, merely relaxing for the treatment session could also have positively affected participant's experiences (Chirico and Gaggioli, 2019). Perhaps the most promising and reliable findings are from a study that compared virtual and real environments in their boosts to creativity (Palanica et al., 2019). Outdoor nature and urban environments evoked similarly high levels of creativity, but simulated nature videos increased creativity much more than simulated urban videos.

Ultimately, further understanding of whether simulations of nature serve as substitutes for nature is warranted, including consideration of confounding factors. For instance, demographic factors can influence participant responses (Hordyk et al., 2015; Riechers et al., 2018; Rigolon et al., 2018b; Tanja-Dijkstra et al., 2018). Also, corollaries to connectedness to nature measures, especially emotional reactivity to discomforting things in nature such as stepping in mud or animal droppings (Shipley and Bixler, 2017; Kharod and Arreguín-Anderson, 2018) and the extent to which someone perceives nature as beautiful (Zhang et al., 2014a,b; Cleary et al., 2017; Passmore and Holder, 2017), may affect the extent to which someone benefits from a VR nature experience. These latter confounding factors are particularly relevant, because they have been relatively neglected in past research.

To address these methodological and conceptual gaps, we test psychological and physiological indicators of mood and restorativeness that result from 6 min of exposure to virtual nature, outdoor nature, or indoor settings without nature while controlling for an array of confounding factors. Our primary goal is to determine whether a single dose of 360-degree nature video exposure yields similar benefits as a single dose of physical nature exposure. More precisely, we aim to test where along a spectrum from no nature exposure to extensive nature exposure the psycho-physiological benefits of virtual exposure fall (see **Figure 1**). We examine mood and restorativeness as outcomes because they are commonly studied outcomes in the literature on physical and simulated nature exposure (McMahan and Estes, 2015). Because individual differences influence how people respond to VR (Anderson et al., 2017) and outdoor nature (Markevych et al., 2017), we are guided by a secondary goal: testing whether the impacts of virtual nature and outdoor nature persist when preferences for nature as well as experiences in nature and VR are taken into account.

MATERIALS AND METHODS

Research Design

The effects of nature exposure on mood and restorativeness were studied with a between-subjects design. Participants were randomly assigned to one of three conditions: (1) an outdoor forest setting; (2) a 360-degree video of that same forest setting replayed in a VR headset with noise-canceling headphones; or (3) an indoor setting with no visual or auditory access to nature (see **Figure 2**). Surveys on preferences toward nature, experiences in nature and VR, and demographic characteristics were conducted before the condition, and surveys on restorativeness were conducted after the condition. Surveys on mood were administered both before and after the condition.

Physiological indicators of emotional arousal were measured using skin conductivity levels (SCL) to evaluate electrodermal activity[1]. Increased SCL can represent positive or negative affective arousal (Gross and Levenson, 1997) so self-report measures are required to determine the valence. We were interested in tonic conductance to represent the effect of continuous exposure to stimuli over several minutes (Dawson et al., 2017). This approach has been previously employed in research that compares 360-degree nature videos with real nature exposure (Kim et al., 2018). To measure SCL, Shimmer GSR+ sensor nodes were attached to the second and fourth finger of the participants' non-dominant hand, and raw data were processed in ConsensysPRO software (Koussaifi et al., 2018) (Shimmer, Dublin, Ireland).

The experiment was run between September and December 2017 at an educational center adjacent to a hardwood forest. The center was located approximately 10 min from the university campus where participants were recruited. The indoor activities were conducted in a climate-controlled room with a thermostat

[1]We also aimed to calculate heart rate variability as a physiological indicator of mood. A photoplethysmography (PPG) sensor was attached to participants' earlobes and connected to the same device that was measuring SCL (Shimmer GSR+). The data collected from this PPG sensor provided an inconsistent signal. Because heart rate variability is extremely sensitive to missing data, we could not report results with confidence (Fairclough and Gilleade, 2014).

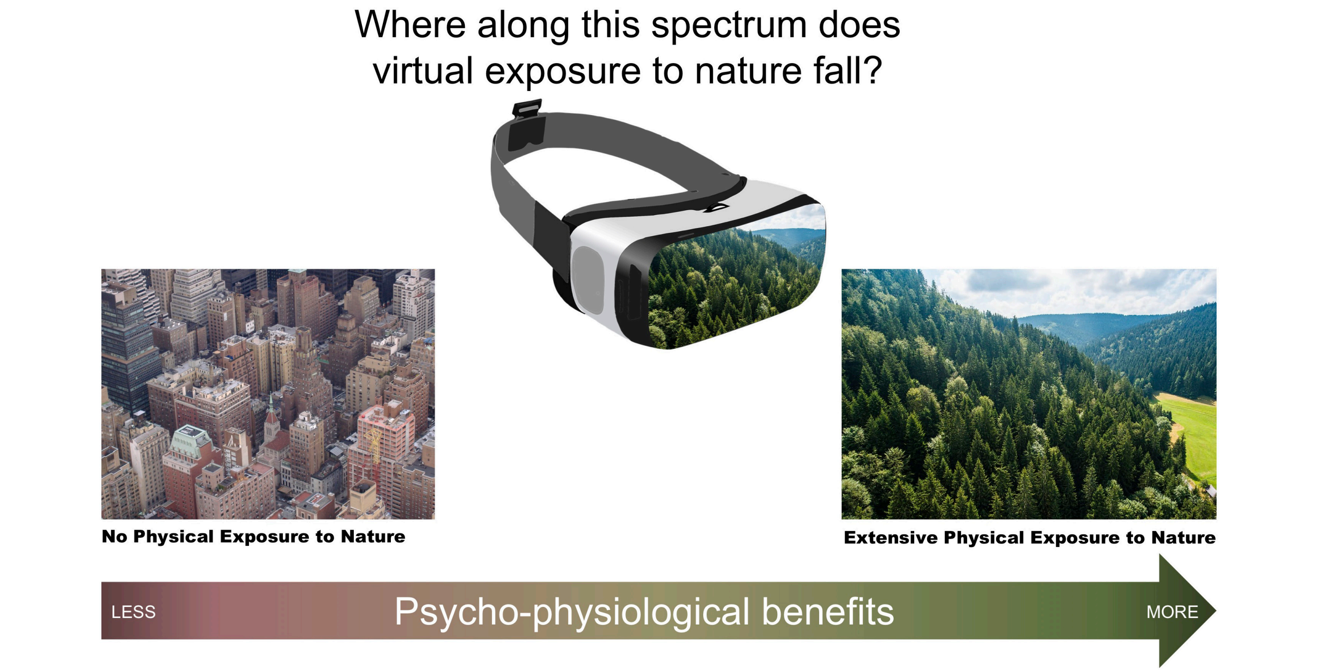

FIGURE 1 | Previous literature is unclear regarding the extent to which virtual nature exposure replicates the psycho-physiological benefits conferred by extensive physical exposure to nature.

FIGURE 2 | Subjects were randomly assigned to one of three conditions. Outdoor subjects **(A)** sat in a foldable chair outdoors in nature and indoor subjects sat in a foldable chair in front of a blank white wall **(B)** or sat in the same chair with a VR headset and noise-canceling headphones **(C)** experiencing the same audio and visual as the outdoor subjects **(D)**. Verbal consent for publication of these images was received from each participant.

set to 72-degrees Fahrenheit. The outdoor activities were limited to rain-free days in September and October 2017 when temperatures were between 70- and 80-degrees Fahrenheit. Temperatures within this relatively narrow range are comfortable for most people and have little effect on between-subject analyses of electrodermal activity or affective valence (Keller et al., 2005; Doberenz et al., 2011; Van de Vliert, 2016). Consistency between the indoor and outdoor activities controlled for potential differences in mood effects based on season (Brooks et al., 2017), prevented participants from becoming distracted by colder temperatures (Bielinis et al., 2018), and limited the confounding effects of the nervous system's response to wider temperature variations (Gladwell et al., 2012). Temperature restrictions outdoors required randomly assigning fewer participants to that condition (see **Supplementary Table S1**).

An initial sample of 190 participants was recruited from a large university in the United States Midwest with an online pre-screening survey. Using a conservative effect size (Cohen's $d = 0.32$; Cohen, 1992) relative to past studies on between-condition mood effects of nature exposure in VR (Schutte et al., 2017), we specified the desired sample size of 30 per condition (90 participants total) at 80% power. Potential participants were excluded if they had a diagnosed mood disorder, took prescription medication for mental health illness, ingested caffeine within 6 h, used tobacco or alcohol or non-prescription drugs that they normally don't take within 24 h, engaged in intense physical activity within 24 h, or had visual or hearing impairments that might interfere with the immersive quality of the VR experience. A total of 143 students were deemed eligible and 98 volunteered to participate in the experiment. Of these 98, several surveys were incomplete and there were cases of equipment failure. Therefore, mood and restorativeness data were generated for 89 participants and SCL data were generated for 65 participants (see **Supplementary Table S1**).

Experimental Conditions

The outdoor condition site was located in a 59-acre bottomland oak-hickory forest that included wildlife such as songbirds, small mammals and moderately dense levels of foliage. This natural area was selected because of its qualities that aligned with restorative concepts indicated in attention restoration theory and stress restoration theory (Ulrich, 1983; Kaplan, 1995). Based on the vegetation layout, the site also provided some visual perceptions of prospect and refuge, which may have made participants feel safe despite being in a densely wooded forest (Appleton, 1996; Jansson et al., 2013). The specific site where the outdoor experiment took place was situated two meters from a small bluff of approximately 4 m in height overlooking a flowing stream. In addition to looking over a body of water, participants experienced aromatic vegetation and heard sounds of bird songs and flowing water. Buildings, vehicles, and people were not visually present, but there were periodic human-made noises.

The VR condition was a 6-min 360-degree video composed of audio and visual stimuli captured at the same location as was shown to outdoor participants. These stimuli were recorded using the Samsung Gear 360 camera and a Zoom H1 external microphone. The videos were stitched together using Gear 360 ActionDirector (Samsung, Seoul, South Korea) and adjusted for brightness and contrast levels in Premiere Pro (Adobe, San Jose, CA, United States). In line with previous research on simulations of natural landscapes, the height of the video was at chest-level (approximately 1.5 m from the ground) (WallGrün et al., 2019) and filmed from a static location to minimize visual-vestibular conflict (LaValle, 2017). The soundscape was identical to the outdoor condition; it included bird songs, flowing water, and intermittent distant sounds of people and vehicles. Participants watched this video in the 2015 Samsung Gear VR headset with a Galaxy Note 5 smartphone inserted. They listened to the soundscape in Audio-Technica ATH-ANC7B QuietPoint Active Noise-Canceling Closed-Back headphones. After the video concluded, a researcher took the headset and headphones off the participant's head and administered the post-condition survey. The video shown to participants is viewable online on a two-dimension computer screen or in a headset at https://youtu.be/zjxafEiJkSw. The audio volume levels in this uploaded video are quieter when heard through a computer than when heard through a VR headset and noise-canceling headphones.

Participants in the control condition received an identical experience as the VR condition with one exception; they were instructed to sit for 6 min in front of a blank white wall. We chose a real control rather than a VR control for two reasons. First, Yin et al. (2018) found no differences between virtual no-nature control conditions and real no-nature control conditions (2018). Therefore, either type of control (virtual or physical) should have been adequate for detecting differences between virtual and real nature exposure. Second, other researchers have already shown 360-degree videos with nature are more beneficial than 360-degree videos without nature, including built environments (Chung et al., 2018; Yin et al., 2018; Yu et al., 2018). The effects of trying to relax in a real indoor setting, in comparison to a virtual or real natural setting, has received less research attention. Including this control condition allowed us to address the central goal of this study–testing whether virtual natural environments yielded similar benefits to real outdoor natural environments–by asking participants to relax without VR technology, access to real nature, or guided relaxation techniques (i.e., meditation or breathing).

Each condition consisted of 6 min of sitting as well as 6 min of walking. For the sitting component, participants were asked to "try to relax and enjoy the setting." We chose 6 min of sitting based on past research showing this length of time is needed to elicit psychological and physiological responses when participants are exposed to natural environments in VR (Anderson et al., 2017; Schutte et al., 2017). The walking component occurred both before and after the sitting component; 3 min of walking was required to travel to and from the educational building to the site where the participants sat outside. Because walking can improve mood in restorative and non-restorative settings (Gidlow et al., 2016), we instructed participants who were assigned to the indoor conditions to walk for 6 min on a 4 m × 3 m green rug before and after their sitting session. This study design approved by the Institutional Review Board at University of Illinois at Urbana-Champaign.

Measures

Benefits From Nature

We measured mood with 27 items from the state Positive and Negative Affect Schedule (PANAS) scale (Watson et al., 1988) on a Likert scale ranging from "Not at all" to "Very much." Both positive ($\alpha = 0.92$) and negative affect scales ($\alpha = 0.85$) maintained acceptable internal consistency (Cortina, 1993). We measured restorativeness with the Perceived Restorativeness Scale ($\alpha = 0.83$) (Hartig et al., 1997). This scale consisted of 11 items that reflected: (1) being away (providing an escape from everyday stressors and routines); (2) extent (being immersed in the environment); (3) compatibility (feeling comfortable in an environment); and (4) fascination (having one's attention captured effortlessly). They were measured on a five-point scale ranging from "Very slightly or not at all" to "Extremely." Physiological arousal associated with changes in mood were measured with continuous skin conductance levels throughout the entire experiment (see **Figure 3**).

Preferences Toward Nature

Two preferences toward nature were measured: disgust and beauty. The former was measured with the Disgust Sensitivity Scale (Bixler and Floyd, 1999). Participants rated the extent to which they felt disgusted by experiences encountered in the natural world (e.g., "getting itchy from dust and sweat on my skin," "having to sit on the grounds in the woods," and "finding a tick crawling up my leg") on a five-point Likert scale ranging from "Not at all disgusting" to "Very disgusting." A total disgust score was calculated from the sum of responses to the 15 items ($\alpha = 0.93$), with higher scores indicating greater levels of disgust.

The extent to which people were associated the natural world with beauty was measured with a four item Natural Beauty Subscale of the Engagement with Beauty Scale (EBS) (Diessner et al., 2008). These items (e.g., "I notice beauty in one or more aspects of nature") were ranked on a seven-point Likert scale from "Very unlike me" to "Very much like me," and a total score was calculated from the sum of all responses ($\alpha = 0.82$).

Experiences in Nature and Virtual Reality

Participant's experiences were measured with two indicators. First, we asked participants whether they had experienced VR before, and if so, how often they had used it. Response categories ranged from 1 ("No, never used it") to 6 ("Yes, more than ten times"). Second, we assessed nature exposure by asking participants whether they had visited a natural area like the one utilized in the outdoor condition in the past year from a single-item measure (Browning et al., 2018). Response categories ranged from 1 ("0 times in the last 12 months") to 9 ("Five or more times per week, for most weeks in the last year").

Demographic Characteristics

We collected data on participant's sex, age, and race. There were two dominant racial/ethnic groups in our sample: non-Hispanic White and non-Hispanic Asian. The dummy-coded race variable used to designate non-Hispanic White can thus be interpreted as pointing primarily to differences between non-Hispanic White and Asian participants in our sample.

Statistical Analyses

Most data analyses were performed in R version 3.4.2 (Vienna, Austria). Normality tests on outcome variables were performed using a visual inspection of QQ-plots, Skewness and Kurtosis with a critical value of 3.0 and Shapiro–Wilks and Anderson-Darling tests with an alpha of 0.05. Positive affect values were normally distributed. Ordered quantile normalization, which combines risk-mapping and shifted logit approximation, indicated that Yeo-Johnson transformations would best normalize pre- and post-condition negative affect values and restorativeness values, which were all positively skewed (Peterson, 2018). Transformed perceived restorativeness values passed all normality tests. Pre- and post-condition negative affect values returned acceptable Skewness and Kurtosis values and relatively normal plots but statistically significant Shapiro–Wilks and Anderson-Darling tests, $p < 0.001$. Therefore, non-parametric tests and tests of heteroscedasticity for regression models with these variables were used.

Descriptive statistics including mean values and standard deviations for outcome variables at each point in time (i.e., before and after the 6-min condition) were calculated for each group to ensure baseline levels were equivalent. The two control variables with continuous measures (disgust and beauty), were compared across groups using one-way ANOVAs. Frequency counts for single-item measures including VR and nature experiences were examined using chi-squared tests to determine whether these behaviors occurred at different frequencies between groups and

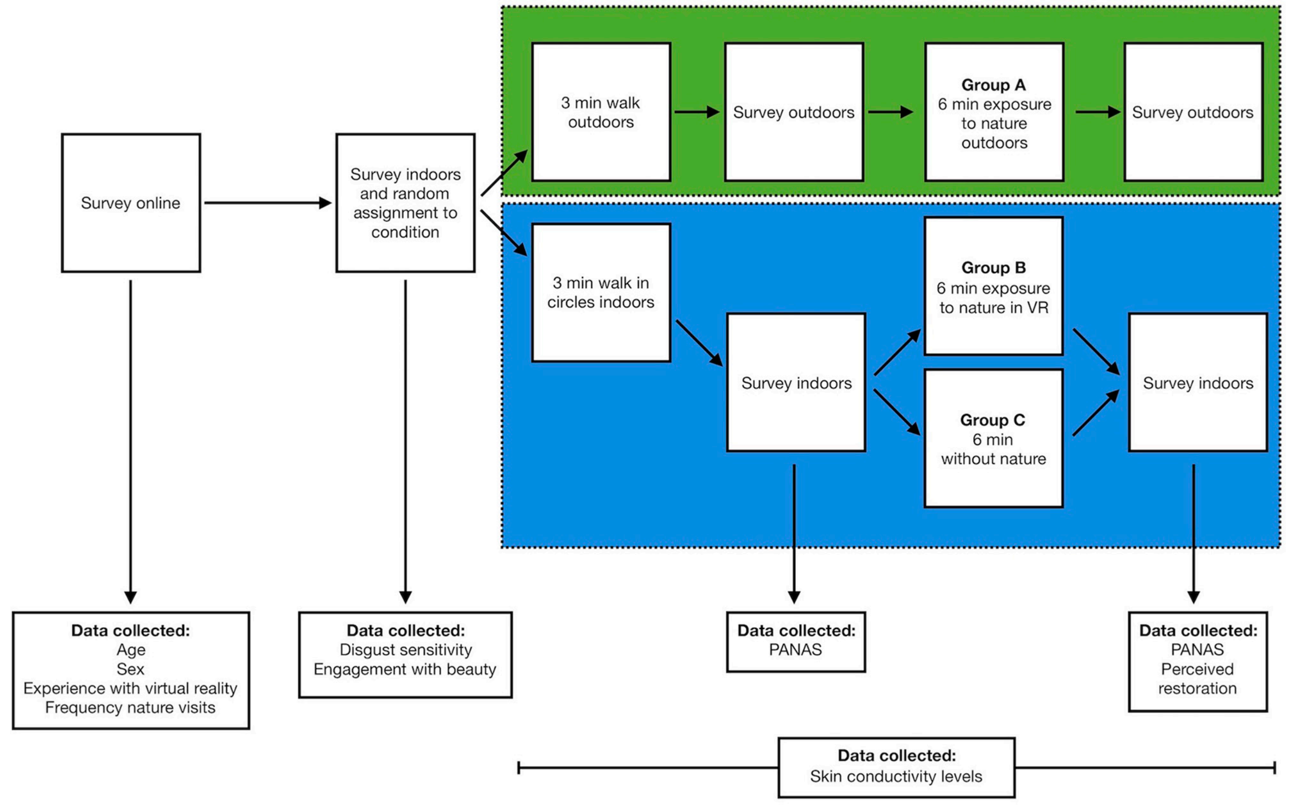

FIGURE 3 | Study design.

to ensure randomized groups had similar experiences. Non-parametric Wilcoxon signed-rank tests were used to examine within group pre- to post-condition differences for negative affect. Paired sample *t*-tests were used to compare within group pre- to post-condition differences for positive affect.

To test for a potential novelty effect of first-time VR users (Leite et al., 2019), we conducted a factorial ANOVA—condition × previous experience with VR—for each of the outcome variables (i.e., perceived restoration, change in positive affect, and change in negative affect; Chirico and Gaggioli, 2019). As a sensitivity analysis, we reran ANOVA models with previous VR experience recorded as a binary variable: "0" no experience ($n = 49$), and "1" = any amount of experience ($n = 33$).

To test for between-group effects, we performed stepwise regressions with post-condition affect and restorativeness as dependent variables. For positive and negative affect, base models included pre-condition affect scores as well as demographic characteristics. For restorativeness, the first model was the same as the models with affect as the dependent variable, but no pre-condition score was added. Second models added the two nature conditions coded as dummy variables with the indoor control condition used as the reference group. Third models added nature and VR-related individual difference variables, including preferences toward nature and experiences in VR and nature. Differences in model fits were compared with ANOVA. Breusch–Pagan tests were used to determine whether coefficients in regression models with non-normally distributed dependent variables (i.e., negative affect) were robust to assumptions of heteroscedasticity.

Trajectories of physiological arousal were analyzed using growth curve modeling in the HLM software program (Raudenbush et al., 2017) (Scientific Software International, Inc., Skokie, IL, United States). Participants' repeated SCL scores (i.e., means for twelve 30 s intervals across the nature or the control condition, natural log-transformed to correct skew) were modeled with linear and curvilinear growth terms to describe participant trajectories. Models were centered at the sixth point in time so that intercepts represented estimated SCL levels at the midpoint of the condition. Linear terms represented the tendency to show increasing or decreasing SCL at that time. Quadratic terms represented the overall SCL dynamic across the 6 min (rising and then falling, flat, or falling and then rising). A second set of models was created to include predictors that could explain differences in SCL trajectories across participants. These included: (a) study condition, and (b) post-condition affect, controlling for pre-condition affect. All models controlled for baseline SCL levels (means across two pre-condition 30 s intervals).

Similar to past analytical approaches to evaluate the psychological benefits of nature simulations, we tested for and removed outliers (Jiang et al., 2016). These were identified by calculating the squared Mahalanobis distance using positive and negative affect, restorativeness, disgust, and engagement with beauty survey responses (Harris et al., 2017). For non-normally distributed outcome variables, transformed values were used. Using a critical value of 3 × SD of the Mahalanobis Distance, we removed four participants from the dataset. Outlier detection was also conducted for our physiological sample using the same critical value and the SCL levels. We removed five participants from that sample. All analyses were re-run without outliers removed, but no differences in the results were found.

RESULTS

Descriptive Statistics

Our sample consisted of 43 male and 39 female participants with a mean age of 20 (*SD* = 1.2). Twenty-nine were non-Hispanic White, 44 were Asian or Asian-American, and the remaining participants were African-American, Hispanic/Latino, or mixed (see **Supplementary Table S2**).

Participants were slightly inclined toward engagement with natural beauty. Mean scores were 5.3 (*SD* = 1.0) on a scale from 1 to 7, with higher numbers representing more engagement. These values did not vary between conditions, $F(2, 79) = 0.046$, $p = 0.95$.

Participants reported moderate levels of disgust sensitivity toward nature. Mean scores were 3.0 (*SD* = 0.94) on a scale from 1 to 5, with higher numbers representing more disgust. The experiences reported to be most disgusting were not experienced by participants who went outdoors. These experiences included roach crawling across hand (*M* = 4.2, *SD* = 1.0), tick biting scalp (*M* = 3.9, *SD* = 1.2), tick crawling up leg (*M* = 3.7, *SD* = 1.3), and accidentally touching a slug (*M* = 3.6, *SD* = 1.3). Again, the average level of disgust sensitivity toward nature did not vary between conditions, $F(2, 79) = 0.071$, $p = 0.93$.

The majority of participants had not experienced VR. Participants reported never using VR (60% of the sample) or using it once (18%), two to three times (16%), four to six times (2%), or six or more times (4%). VR experiences did not vary between conditions, $\chi^2 (8) = 10.5$, $p = 0.23$.

Approximately half of the participants had visited a nature-based park more than once but less than ten times in the last 12 months. Only 6% reported never visiting a park in this period, with 10% reporting one time, 30% 2–5 times, 26% 6–9 times, 15% 10–14 times, and 13% 2 times per month or more in the past year. Reported visitation rates did not vary between conditions, $\chi^2 (16) = 20.9$, $p = 0.18$.

Potential for Novelty Effect

We found no significant interaction effect of condition with previous VR experience on perceived restorativeness, [$F(2,76) = 1.96$; $p = 0.148$]; change in positive affect [$F(2,76) = 2.02$; p = 0.118]; or change in negative affect, [$F(2,76) = 1.59$; $p = 0.210$]. In sensitivity analyses with previous VR experience recoded as a binary variable, the interaction terms were not significantly significant in models with perceived restorativeness or in models with negative affect, $p > 0.05$. We found one significant interaction term in models with positive affect, [$F(2,76) = 4.11$, $p = 0.0202$]. However, Tukey post-hoc comparisons indicated no significant difference in changes in positive affect between people with VR experience and people without VR experience: for the group with no VR experience, −0.22 (*SD* = 0.45); for the group with some VR experience, 0.17 (*SD* = 0.51); and the difference between the two groups = −0.386 [−0.880, 0.108], $p = 0.214$.

Mood Effects

The indoor control condition and the outdoor nature conditions – but not the VR nature condition – resulted in statistically significant changes in positive affect. The mean positive affect for the outdoor group increased from 3.37 (*SD* = 0.49) before the condition to 3.54 (*SD* = 0.66) after the condition, $t(21) = 2.14$, $p = 0.044$. In contrast, the mean positive affect for the control group decreased from 3.00 (*SD* = 0.68) before the condition to 2.42 (*SD* = 0.71) after the condition, $t(29) = -4.94$, $p < 0.001$. No change in the VR group was present, $t(29) = 0.28$, $p = 0.78$.

Table 1 shows how demographics, nature exposure, and other potential confounders predicted post-condition positive affect. The base model with demographics and pre-condition levels explained 56% of the variance. Adding the nature conditions increased model fit and explained 13% more variance (**Table 1**, Model 2), $F(2) = 20.1$, $p < 0.001$. Both nature condition effects were positive and statistically significant, $p < 0.001$, indicating VR nature and outdoor nature resulted in higher positive affect scores relative to the control. Differences between conditions remained statistically significant after adjusting for preferences toward nature and experience in nature and VR experience (**Table 1**, Model 3). This fully adjusted model explained 73% of the variance in the post-condition positive affect scores, which was more than the previous model, $F(4) = 3.8$, $p = 0.0073$. Engagement with beauty was the only predictor beyond condition and pre-condition levels that predicted post-condition affect, $p = 0.001$.

In contrast to positive affect findings, we found a statistically significant reduction in negative affect across all three conditions. Mean negative affect values dropped from before the condition to after the condition as follows: for the outdoor group, 1.23 (*SD* = 0.20) to 1.17 (*SD* = 0.23), $p = 0.034$; for the control group, 1.38 (*SD* = 0.27) to 1.20 (*SD* = 0.57), $p < 0.001$; for the VR group, 1.32 (*SD* = 0.37) to 1.24 (*SD* = 0.46), $p = 0.030$. Regression models with demographics and pre-condition negative affect levels explained 57% of variance, $F(77) = 28.6$, $p < 0.001$; however, adding the two nature exposure conditions to the model did not improve the model fit, $F(75) = 1.79$, $p = 0.17$. The variance of the errors in this model displayed moderate heteroscedasticity (Breusch–Pagan test value = 18.7(10), $p = 0.045$). In combination with paired sample *t*-tests, these findings suggest no difference between conditions in changes in post-condition negative affect levels was likely.

TABLE 1 | Results from regression of post-condition positive affect on demographics (model 1), condition (model 2), and additional confounders (model 3) following virtual and physical nature exposure (no nature exposure serves as the control condition).

	Model 1			Model 2			Model 3		
Predictors	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
Intercept	0.40	−1.88 – 2.69	0.730	0.90	−1.03 – 2.83	0.362	0.48	−1.54 – 2.50	0.642
Baseline positive affect	**0.90**	**0.69 – 1.10**	**<0.001**	**0.83**	**0.66 – 1.01**	**<0.001**	**0.78**	**0.62 – 0.95**	**<0.001**
Age	−0.02	−0.12 – 0.09	0.719	−0.05	−0.14 – 0.04	0.251	−0.06	−0.14 – 0.03	0.201
Gender	0.04	−0.21 – 0.29	0.762	0.01	−0.20 – 0.22	0.930	−0.05	−0.27 – 0.16	0.634
Race (white)	**0.29**	**0.03 – 0.56**	**0.035**	0.20	−0.03 – 0.43	0.091	0.14	−0.09 – 0.37	0.247
VR treatment				**0.52**	**0.27 – 0.76**	**<0.001**	**0.53**	**0.30 – 0.76**	**<0.001**
Outdoor treatment				**0.77**	**0.50 – 1.05**	**<0.001**	**0.79**	**0.53 – 1.05**	**<0.001**
Disgust sensitivity							−0.06	−0.19 – 0.07	0.398
Engagement with beauty							**0.18**	**0.07 – 0.28**	**0.001**
Frequency of nature visits							0.01	−0.06 – 0.07	0.872
Experience using VR							−0.06	−0.15 – 0.03	0.174
Observations	82			82			82		
R^2/adjusted R^2	0.580/0.559			0.714/0.691			0.765/0.731		

Statistically significant estimates at p < 0.05 in bold.

Restorativeness

VR and outdoor nature exposure conditions predicted greater restorativeness than the control condition even after adjusting for demographics and other potential confounders (see **Supplementary Table S3**). The model with demographics predicted 15% of the variance in restorativeness and adding the two condition variables explained an additional 14%. This change in model fit was statistically significant, $F(2) = 12.5$, $p < 0.001$. Both outdoor and VR nature conditions were positively and statistically significantly associated with restorativeness relative to the control. Adding preferences toward nature and experience in VR and nature explained another 9% of the variance, which was a statistically significant improvement in model fit, $F(4) = 2.94$, $p = 0.026$. Similar to positive affect regression models, engagement with beauty was the only significant predictor of restorativeness other than the condition in the fully adjusted model, $p = 0.008$.

Physiological Effects

Compared to the control, participants in the two nature conditions tended to show higher SCL levels and a more steadily increasing slope over time. The control condition showed a different trend: a decrease followed by an increase (see Model 1 in **Table 2** and **Figure 4A**). Follow-up analysis with outdoors as the comparison condition showed no significant differences in SCL trajectories between the two nature conditions. SCL trajectory patterns related to nature conditions were further found to relate to post-condition positive affect but not to negative affect (see Model 2 in **Table 2** and **Figure 4B**). Those participants who showed continuously increasing SCLs and ultimately higher SCLs mid-condition reported higher levels of positive affect afterward. Generally, these findings suggest that increasing physiological arousal during nature exposure–outdoors and, to a lesser extent, in VR—was associated with the increase or maintenance of positive affective states.

DISCUSSION

A fundamental limitation to our current understanding on human-nature interactions relates to how modern nature simulations replicate the benefits of physical nature exposure. Given the number of people with limited access to outdoor nature and the expected increasing limited contact with restorative nature, VR is an innovative way to provide at least some of the same health benefits as going outdoors. The extant literature on virtual nature suggests it does not replicate real nature exposure, but these findings come from pictures and videos on screens, not highly immersive 360-degree VR environments. The latter has been shown to produce more beneficial effects than the former (Liszio et al., 2018). However, the results of previous VR studies are confounded by motion sickness, inadequate controls, or limited sensory inputs from the real nature treatment. Building on previous research that has demonstrated nature videos in VR generally provide beneficial effects (White et al., 2018) and that these effects are superior to those effects elicited from videos of built environments in VR (van den Berg et al., 2016; Tanja-Dijkstra et al., 2018; Hedblom et al., 2019), this is the first study to compare outdoor nature with virtual nature that has attempted to overcome these previous limitations while also adjusting for a range of individual differences related to nature and VR.

We compared changes in mood, restorativeness, and physiological arousal after 6 min of exposure to outdoor nature, VR nature, and an indoor control in a sample of healthy undergraduate students. Nature exposure outdoors boosted positive affect and VR preserved positive affect compared with sitting indoors with no nature exposure, which diminished positive affect. Virtual and outdoor nature showed higher

TABLE 2 | Study condition and post-condition affect related to skin conductance trajectories.

Predictor	Intercept (SCL level mid-condition) γ, p	Linear Slope (rate of change mid-condition) γ, p	Quadratic Slope (curvature across condition) γ, p
Model 1			
Outdoor (vs. control) condition	**0.175, 0.057**	**0.039, 0.004**	**−0.004, 0.043**
Virtual (vs. control) condition	**0.203, 0.041**	0.028, 0.076	−0.003, 0.288
Model 2			
Positive affect	**0.156, 0.022**	**0.036, <0.001**	**−0.003, 0.041**
Negative affect	−0.150, 0.092	−0.002, 0.910	0.003, 0.126

Statistically significant estimates at $p < 0.05$ in bold.

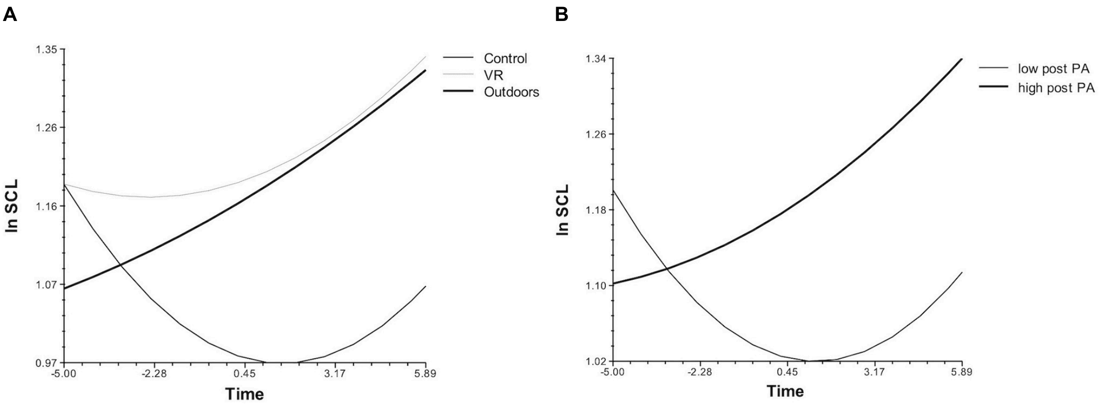

FIGURE 4 | Skin conductance level (SCL) trajectories differed between control and nature conditions **(A)** and by post-condition positive affect levels after controlling for pre-condition positive affect levels **(B)**. Lines on the left **(A)** depict predicted trajectories in the control, outdoor nature, and VR nature conditions. Lines on the right **(B)** depict high (75th percentile) and low (25th percentile) values of reported positive affect in the two nature conditions (outdoors or VR). In both graphs, time represents 30 s intervals centered on the midpoint of 12 SCL measurements during the 6-min condition.

post-condition positive affect levels even after adjusting for preferences toward nature, experiences in VR and nature, and demographics. Outdoor nature and virtual nature were rated as equally restorative and both resulted in physiological arousal associated with positive affect. Engagement with beauty (i.e., the extent to which someone recognizes the natural environment as aesthetically pleasing) and race measured as the percent not identifying as non-Hispanic White were the only covariates positively associated with mood outcomes, although the effects of race attenuated in fully adjusted models. Disgust sensitivity, experience in nature or VR, age, and gender were non-significant.

This study extends previous research findings on virtual nature and its impact on mood. Similar to other studies with 360-degree videos of VR nature (Anderson et al., 2017; Schutte et al., 2017), we observed that positive affect remained constant in the virtual condition while negative affect decreased. This finding complements a growing body of research that suggests negative affect is more commonly impacted by simulated nature exposure than positive affect (Lohr and Pearson-Mims, 2000; van den Berg et al., 2003). There are multiple reasons why positive affect could show little change after a simulated nature experience. Participants might become bored or disconnected while viewing pictures or videos of environments, and boredom and disconnection are incompatible with positive affect (Kjellgren and Buhrkall, 2010; Brooks et al., 2017). Also, stress reduction theory explains that natural landscapes promote wellbeing in part because of human's unconscious identification with these landscapes for their evolutionary needs (Ulrich, 1983). Being outdoors in a restorative natural environment with food, water, shelter, and raw materials can help people survive. People would not be able to access these elements in a virtual natural environment. Simulated nature might primarily benefit negative affect because previous research (Lohr and Pearson-Mims, 2000; van den Berg et al., 2003) and attention restoration theory (Kaplan, 1995) suggest that if people feel like they are away from their everyday demands through visual access to nature, these feelings can interrupt cognitive demands and maladaptive patterns of thought. Such demands and patterns manifest themselves in reductions of negative affect but not necessarily increases in positive affect (Golding et al., 2018). We found that positive affect was greater in the VR condition than in the control condition. This aligns more with the findings from outdoor nature research than with simulated nature research (McMahan and Estes, 2015; Neill et al., 2018). Therefore, it is possible that immersive 360-degree videos of nature, in the absence of cybersickness, provide a more realistic and beneficial experience across multiple domains of mood (i.e., positive and negative affect) than other types of simulations.

Unexpectedly, our control condition also showed reductions in negative affect. Study recruitment materials mentioned the restorative effects of environments, and participants may have expected relief by relaxing in the indoor control environment despite its lack of restorative elements (Flowers et al., 2018). Also, our college-aged sample of participants could have experienced relief from smartphone restriction. The corollary to smartphone restriction – constant smartphone use – is associated with higher levels of negative affect (Horwood and Anglim, 2019). Studies on short breaks from smartphone use is limited, and the potential anxiety-provoking experiences related to "fear of missing out" (FOMO) from social media has largely been studied during longer periods of restriction than 6 min (Eide et al., 2018; Stieger and Lewetz, 2018). Investigations on the mood effects from short-term smartphone restriction is needed to investigate this potential explanation.

Contrary to previous research on physiological responses to natural environments, we observed an increase in skin conductance during exposure to nature. Skin conductance has largely been used to measure the impacts of different environments (i.e., built or natural) on recovery after an induced stressful or cognitively demanding task (Berto, 2014; Frumkin et al., 2017). In such scenarios, we would expect a drop in arousal levels as the sympathetic nervous system recovers from the challenge. Our study's findings represent arousal in response to a period of exposure to a natural environment compared with a neutral built environment. Thus, increased arousal in the nature condition may reflect interest in and/or engagement with natural visual and auditory stimuli that supported positive affect maintenance, as opposed to boredom and/or disengagement that degraded positive affect in the neutral built condition. This result is consistent with studies on emotional reactivity to nature exposure that do not present a stressor prior to nature exposure (Felnhofer et al., 2015; Chirico et al., 2017).

Strengths and Limitations

The major strength of this study is our employment of a novel technology that has promise for mental health promotion, given its low cost and convenience. While some recent research has used this technology, the effects of outdoor nature exposure adjusted for a range of individual differences related to nature and VR experience, preferences, and cybersickness have not been examined. Another strength of this study is its comparison between outdoor nature exposures and VR nature exposure using a 360-degree video from the outdoor nature exposure location, which has been done in only a few other studies (Calogiuri et al., 2018; Yin et al., 2018). Furthermore, we used a between-subject design, which removed cross-over effects potentially present in previous research that has compared virtual nature to outdoor nature.

Our study was limited by our choice of a healthy, predominantly White and Asian sampling frame that had ready access to outdoor nature. The limited age range (18–27) represents a population likely comfortable with and inclined toward the use of VR (Roberts et al., 2019). While we did not observe differences in affective responses between participants with experience in VR and participants without such experience, populations less familiar or accepting of electronic technology may be less likely to benefit from a sensory-rich simulated environment like VR without adverse events, safety concerns, or poor adherence rates (Miller et al., 2014). We cannot assume similar effects would be seen in older populations, non-healthy (i.e., clinical) populations, or individuals without ready access to outdoor nature, including people with physical limitations. Because most experimental research involving responses to natural environments (Holt et al., 2019; Mygind et al., 2019) and VR (Oh et al., 2016) use college student populations, our findings still build on the existing body of literature on the therapeutic potential of 360-degree nature videos in VR.

Ideally, our study would have had a fourth condition—a 360-degree video of a complex scene without natural elements—to test whether nature or novelty was responsible for the observed effects. While the current results suggest previous experience with VR did not influence the restorative outcomes of simulated natural environments, this would have been better tested directly with an additional control condition. Limitations to budget and timeline allowed random assignment of participants to only three conditions, however.

Opportunities for Future Research

This study can serve as a springboard for a line of future research focused on the benefits of exposure to nature through mobile VR technology. We recommend testing the effects of repeated exposures to VR nature. The preservation of positive affect that we observed may have been a result of not just the restorativeness of the 360-degree nature videos but also the novelty of VR. Indeed, past research has found psycho-physiological responses to virtual environments (Jang et al., 2002; Leite et al., 2019). Incorporating heart rate variability (HRV) would be a useful next step in interrogating mood-relevant arousal because HRV is a low-cost and non-invasive measure to measure parasympathetic activation (see the model of neurovisceral integration, Thayer et al., 2009). Future research should also inform decisions about the necessary "dosages" of outdoor and virtual nature needed to elicit clinical effects. Laboratory studies could incorporate more sensory inputs than we have done, such as the smells of nature (Hedblom et al., 2019), to create more immersive and potentially restorative experiences, or overlaying complementary therapeutic modalities such as slow-paced breathing and biofeedback (Blum et al., 2019). Studies in clinical settings or densely populated areas where residents do not have safe access to nature could examine whether these potential users would benefit from VR nature. To control for potential expectancy and smartphone restriction effects, research could combine restorative environmental exposures with opportunities to engage in social media during the control conditions (Jiang et al., 2018). Alternatively, researchers could use alternative methods to laboratory studies, such as ecological momentary assessments (Beute and de Kort, 2018; Isham et al., 2018), to reliably capture the impacts of nature exposure during daily living. We are aware of only one study that has compared psychological and physiological responses to both physical and virtual environments that include either predominantly built or natural elements (Yin et al., 2018). The current study employed a physical control condition, but future work could use a VR control condition to ensure that nature is responsible for the observed affective response. Last, mood changes may not represent the full suite of cognitive and emotional benefits of nature (Gamble et al., 2014). As such, we recommend additional measures (i.e., attention depletion tasks before each condition and cognitive functioning tasks after each condition) to compare the benefits of virtual and real nature.

CONCLUSION

Six minutes of nature exposure in mobile VR headsets produced similar effects as 6 min of outdoor nature exposure. Both of these conditions were superior to sitting indoors with no exposure to nature. Both virtual and outdoor nature exposure resulted in a pattern of increasing physiological arousal associated with higher positive affect, although only the outdoor nature condition showed measurable increases in positive affect. Short and isolated exposure to a 360-degree video of nature may provide an emotionally beneficial alternative to visits to outdoor nature in healthy student populations who might not otherwise access restorative outdoor environments. Further research is needed on repeated exposure to virtual versus nature-based experiences in other populations.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study involved human participants and was reviewed and approved by the University of Illinois at Urbana-Champaign [Institutional Review Board (approval #17488)]. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MB and KM conceived of and conducted the study with assistance from SL. HL completed the physiological data analysis. MB collected all data and analyzed the non-physiological data. All authors, including CR and SL, contributed to framing and writing the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02667/full#supplementary-material

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Place Identity: How Far Have We Come in Exploring Its Meanings?

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In order to synthesize the extensively studied place identities and their meanings, this paper reviews how researchers have conceived and deconstructed place identity. CiteSpace, a scientometric tool for visualizing and analyzing trends and patterns in scientific literature, is used to identify the active topics and new developments of publications in place identity. The data set input into CiteSpace consists of 1,011 bibliographic records retrieved from the core database of Web of Science with a title search of the articles published between 1985 and July 2019. The scientometric review reveals the extensive applications of place identity in various topics. Studies in this field experienced an active exploration in plural disciplines after 2000, and the hot area gradually concentrated on the discipline of humanities and social sciences after 2010 and shifted toward place marketing until now. A network of co-cited references identified seven dominant research clusters, of which the research on the influence of place identity on social actors' attitudes and behaviors is most prominent and the research on the effects of physical environment change on place identity captures the latest emerging area. Versatile meanings of place identity are witnessed in different clusters and articles of a cluster. These meanings are intertwined in shaping the knowledge base of thematic concentrations. To supplement the scientometric analysis, a deep survey on measuring methods and roles of place identity in the contents of academic articles was done to trace knowledge connections between different empirical understandings of place identity. Finally, this paper summarizes the meanings of place identity in four dimensions and in turn offers some suggestions for further research directions.

Keywords: place identity, meanings, CiteSpace, scientometric, review

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INTRODUCTION

Place identity is a versatile concept upon which many psychological theories of human–environment relations are built (Zimmerbauer et al., 2012; Gieseking et al., 2014). The social constructivist theory of place identity sheds light on individuals' subjective perceptions of geographical space, providing valuable insights for studies of various disciplines, such as geography, sociology, psychology, environmental sciences and ecology, public administration, spatial planning, and so on (Haartsen et al., 2000). As broadly acknowledged, place identity was initially introduced by Proshansky (1978), who defined place identity as "those dimensions of self that define the individual's personal identity in relation to the physical environment by means of a complex pattern of conscious and unconscious ideas, feelings, values, goals, preferences, skills, and behavioral tendencies relevant to a specific environment" (Proshansky, 1978, p. 155). Proshansky's view on place identity has been widely referred to. Another dominant explanation of place identity can be found in most of Paasi's articles (Paasi, 1986, 1991, 2002c, 2003, 2009a,b). He thought it would be beneficial to distinguish analytically two aspects of place identity, namely, place identity of a place and people's place identity. The former refers to those features of nature, culture, and people that are used in the discourses and classifications of science, politics, cultural activism, regional marketing, tourism, governance, and political or religious regionalization, to distinguish one place from others. The latter refers to the identification of individuals with a place. The definitions of place identity by early leading scholars, such as Proshansky and Paasi, from different disciplines have influenced the formation of the versatile meanings of place identity to a great extent.

There are many other scholars who have contributed a lot to enriching the meaning and theory of place identity (Relph, 1976; Tuan, 1977; Peterson, 1988; Saleh, 1998; Twigger-Ross et al., 2003; Carrus et al., 2005; Huigen and Meijering, 2005; Hauge, 2007; Groote and Haartsen, 2008; White et al., 2008). However, in most occasions, their conceptual foundation of place identity revolves on either the place identity of a place or people's place identity. They seldom notice both sides of place identity, or at least, there is a paucity of empirical studies that have discerned the two sides of place identity. Academic journals have witnessed increasing publications in relation to place identity over the last 40 years, particularly since 2006, as shown in **Figure 1**. Nevertheless, few studies have reviewed and elaborated the versatile meanings of place identity. Limited arguments in a few studies are available on the relationship between these meanings. For example, Paasi (1986, 2002c) used "subjective identity of a region" to connect the two aspects of regional identity. The "subjective identity of a region" refers to images held by the people living in and outside the region, which resemble regional consciousness. Few studies proposed that individuals' identification with a place can be reflected in the identities that they ascribe to the place and are subsequently incorporated into their own identities (Rijnks and Strijker, 2013). However, these intricate debates on the analytical interactions between place, people, and place identity make the meanings of place identity even more confusing. An additional obstacle to the understanding of place identity is the widely complained-about unclear relations between place identity and other environmental psychology concepts, such as place attachment, rootedness, sense of place, place dependence, and place satisfaction (Lewicka, 2011; Xu et al., 2015). Distinctions between these concepts have never been unanimously agreed upon and are still under discussion today.

Another point that might have also caused a fuzzy understanding of place identity is the interchangeable use of "region" and "place" in articles about place identity. Region is usually considered by geographers as a larger unit than place (Entrikin, 1991). Some scholars deem region as historically contingent social processes that occur at various spatial scales (Paasi, 1991, 1996, 2004). Compared with region, place is conceptualized more flexibly, without any presuppositions of scale. It has no essence but is open, fluid, and contested. Place is positioned in complex ways in power geometries and experienced in different ways by different people (Massey, 1994, 1995). The broad categories make "place" increasingly preferred by geographers today (Paasi, 2002b). While actors operate and (re)construct identities across scales, the link of identity to either the omni-scale region or the scale-free place can both hold and justify their positions (Paasi, 1996). Numerous articles titled with either "regional identity" or "place identity" can be searched in any journal database. Some of them may have a clear disciplinary background; for example, "regional identity" papers fit into geography, while "place identity" papers, into environmental psychology. However, there also exists chaos where mixed meanings of place identity are embodied in these two kinds of articles. Therefore, we include both of them in this review work, and in the rest of this article, the term "place identity" will be used primarily as a substitute for "regional identity."

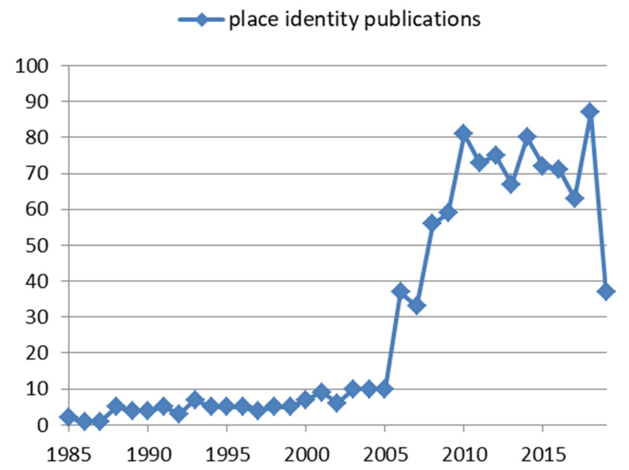

FIGURE 1 | Number of publications on place identity from 1985 to July 2019. A total of 1,011 bibliographic records were obtained in the core data set of Web of Science with a title search for "place identity" or "regional identity" or "regional identities" between 1985 (the earliest year for data available in the core data set) and 2019.

Different understandings of place identity and consequent divergent methods of measuring this construct make the accumulation of knowledge in this domain difficult (Lewicka, 2011). The emerging increment of publications in which numerous roles of place identity have been claimed makes it tough to grasp a coherent intellectual landscape of this area, if it exists. In order to synthesize the extensively studied place identities and their meanings, this work reviews how the literature has conceived and deconstructed place identity. We intend to guide audiences through the development of place identity since its introduction by Proshansky. The emphasis will be on sketching an overall intellectual landscape and investigating the active topics and new developments. More efforts will be paid to a deep examination of the measures and roles of place identity for tracing knowledge connections between different empirical understandings of place identity.

In the next sections, we first use CiteSpace to identify the active topics and new developments of publications on place identity. CiteSpace is a visual analytic system for visualizing emerging trends and critical changes in scientific literature (Chen et al., 2014a,b). Compared with a traditional literature survey, which relies on domain experts' insights and selections of publications, CiteSpace adopts a computational and visual analytic approach drawn from the field of scientometrics and information visualization and can reach a much broader and more diverse range of relevant topics (Chen et al., 2014a,b). Our data set input into CiteSpace consists of 1,011 bibliographic records that are derived from the core database of Web of Science (WoS) with a title search for "place identity" or "regional identity" or "regional identities" between 1985 (the earliest year for data available in the core data base) and July 2019. Each bibliographic record contains the metadata of a published article, including the authors, the title, the abstract, the keywords, and the references with relevant information. In total, 31,307 references are cited by these articles. The examination of the measures and roles of place identity is based on some representative articles selected according to the analysis results generated by CiteSpace.

MEANINGS OF PLACE IDENTITY

People's Place Identity

On an individual's identity card, there is always information about where he or she is from. Everybody in the world belongs somewhere. Although the first impression an individual gives to others is always his or her physical appearance, such an impression would often coincide with the assumption of the place one comes from. For example, people with yellow skin and black hair would be judged as Asian. Therefore, we may realize that man is not simply a physical creature but mostly shaped by relationships, be they social, cultural, environmental, or others. The process by which other people judge you on your appearance is an expression of social and cultural relationships, as they are defining you as different from themselves. The influence that a place imposes on an individual's identity is one of those relationships, and it constitutes part of the individual's selfhood (Basso, 1996, p. 146).

In the late 1970s, to enlighten people on the importance of places influencing the formation of individuals' identities, the term "place identity" was introduced by researchers within the interdisciplinary field of environmental psychology (Proshansky, 1976, 1978; Hauge, 2007). It is described as individuals' incorporation of places into the larger concept of self (Proshansky et al., 1983). The work of Proshansky et al. (1983) has been criticized for their tendency to emphasize the individualistic dimensions of place identity (Dixon and Durrheim, 2000). This shortcoming has been mitigated by the later work on place identity, which suggested a genuinely social understanding of place identity by showing how places might become significant and contested arenas of collective being and belonging (Bonaiuto et al., 1996; Devine-Wright and Lyons, 1997; Dixon and Durrheim, 2000).

Despite the extensive studies on place identity after Proshansky, the theory of place identity is less developed (Bonaiuto et al., 1996). On the one hand, unlike gender, race, or nationality, which constitutes one category of identity, place contains symbols of many different social categories and personal meanings and represents and maintains identity on different levels and dimensions (Hauge, 2007). In other words, place is a component of diverse sub-identity categories, which makes the term "place identity" difficult to operate. When researchers make place identity the focus of their studies, they seldom follow the theoretical framework developed by Proshansky and his colleagues (Proshansky, 1978; Proshansky et al., 1983; Proshansky and Fabian, 1987). It is often referred as a term to describe a subjective feeling of identification with home, a neighborhood, or some larger space (Twigger-Ross et al., 2003; Carrus et al., 2005; White et al., 2008).

On the other hand, along with place identity, there are a number of other constructs developed by environmental psychologists to define and measure individuals' relations with places, such as place attachment (Giuliani and Feldman, 1993), place dependence (Stokols and Shumaker, 1981), sense of place (Lalli, 1992), and so on. There has been no universal agreement on the relationships between these constructs (Fresque-Baxter and Armitage, 2012). White et al. (2008) saw place identity and place dependence as two dimensions of place attachment when they studied the effect of prior experience with setting and place attachment on visitors' perceptions of recreation impacts. However, Bleam (2018) found that place identity is more than a sub-construct of place attachment. Hernández et al. (2007) viewed place identity and place attachment as different constructs. They thought place attachment develops before place identity. They contended that "one person could be attached to a place but not be identified with it," and "someone could have a high personal identity with a place and not a high place attachment." Hernández et al. (2010) argued that "place attachment is an affective–emotional bond with residence places, whereas place identity is a cognitive mechanism, a component of self-concept and/or of personal identity in relation to the place one belongs to." Antonsich's (2010) work pointed out the terminological confusion of these place-based concepts. He summarized that sometimes, place attachment is treated as a synonym of place identity, correlated with it or subsumed within it, or occasionally as a prerequisite. Sometimes, both place identity and place attachment are instead treated as components of sense of place (Jorgensen and Stedman, 2001). In other cases, place attachment is described as a superordinate category (Kyle et al., 2004). Chow and Healey's (2008) argument is consistent with Antonsich's findings. They noted that place attachment is subsumed under place identity in some cases, while some others view place identity as a form of attachment or consider both identity and attachment as dimensions of sense of place. This consensus is shared by Hernández et al. (2007) as well, who identified four different relations between place attachment and place identity according to their review of previous research. Other proposals suggest grading the sense of place. Shamai (1991) divided the sense of place into seven levels, in which attachment is a phase prior to identification.[1]

Confusion and overlap of the concepts that define emotional bonds to places, along with the multidimensional meanings of place itself, lead to the anxiety and criticism on the vague meanings of place identity (Hauge, 2007; Lewicka, 2008). Nevertheless, it has filled a gap in environmental theory and research, through bringing forth the idea that identity is formalized against the backdrop of physical environment (Bonaiuto et al., 1996; Hauge, 2007).

Place Identity of a Place

Place identity ascribed by people to a place is constructed to differentiate one place from others. Differences between places are attributed or perceived by inhabitants living in or outside of those places. It is, to some extent, if not entirely, a subjective social construct based on objective physical settings.[2] In this sense, the meaning of the construct "place identity" of a place resembles that of the construct individual's "place identity" in that both of them are developed to describe subjective cognition about places.

As to the question of what place identity of a place is, the answer is still not clear, though it has been, for a long time, a frequently mentioned term in geographical research. Paasi (2001, 2002a,c, 2003, 2009b) argued that place identity refers to those elements of nature, culture, and regional life (inhabitants, people, or population) that distinguish a region from others. Groote and Haartsen (2008) defined place identity as a combination of physical and man-made processes, specific elements and structures in places, and meanings ascribed to places. The elements that have been referred to by studies as components of place identity indeed cover almost every aspect of a place. In other words, place identity can be anything that makes a place identifiable within the spatial system. There are no fixed components of place identity. Language is one of the most popular features to make places distinctive. Saleh (1998) used physical configuration of places or architectonics to describe place identity of Saudi cities, where local images are enhanced to meet individual and public needs. What's more, people do not discern places in the same way. They perceive identities of places differently and differentiate them by drawing on different elements, such as physical features, cultural attributes, historical associations, experiential ties, and so forth (Peterson, 1988).

In many cases, the vague meaning and uncertain components of place identity make researchers map it by simply tracing unique features as indicators of place identity of that area. Paasi (2009b) criticized that it may lead to a rather "loose use" of place identity in research when any of these features is regarded as an illustration of place identity. People's consciousness of a place should not be overlooked for understanding the identity of that place. Place identity comprises not only a material basis but also a "mental sphere" (Knapp, 2006). Place identity is formed after the place has achieved an established status in both the spatial structure of the society and its social consciousness (Paasi, 1991). From this view, Paasi (1986, 2002c) argued that subjective images and objective classifications are the two subcategories of place identity.

Compared with tracing indicators of place identity, the intention to claim place identity is sometimes considered as a more important matter (Billig, 1995). Identities are ascribed to a place by social actors who have different knowledge, interests, or power in that place. How place identities are constructed in discourses reveals partly the power balance between claimants in the political arena (Haartsen et al., 2000; Paasi, 2002c, 2003). Therefore, place identities are contested. What's more, place identity should be understood as a dynamic process (Haartsen et al., 2000; Paasi, 2001). The formation of place identity is a process of shaping territorial boundaries, symbolism, and institutions (Paasi, 2003). Place consciousness can be strengthened during that process. Perceptions and understanding of the place identity of a place are often interpreted in narratives or discourses. Discourses about place identity are representations of claimants' memories of the past, images of the present, and often, utopias of the future (Paasi, 2001).

ACTIVE TOPICS AND NEW DEVELOPMENTS IN PLACE IDENTITY

A Lightweight Survey of Major Topics

Two polygonal tree maps (see **Figures 2**, **3**), known as foam trees, were generated by Carrot2 to provide an instant and primary detection of major topics in the studies of place identity. Carrot2 is an open source search results clustering engine that can automatically organize small collections of documents from various search sources into thematic categories[3]. **Figure 2** shows a foam tree based on the 113 results of a web search with the keywords "place identity." The foam tree in **Figure 3** was derived from the 1,011 bibliographic records of WoS, which were converted to the required format of Carrot2 prior to the data input.

With the views generated by Carrot2, the lightweight survey of major topics in the literature on place identity provides a useful basic reference to how the term "place identity" is generally conceived (Chen et al., 2014a). As shown in the two figures, *psychology, cultural identity, role, identity theory, identity development or processes, identity construction,* and *place attachment* are among the leading topics in the literature on place identity. Among other major topics, studies on place identity at different spatial scales constitute a certain portion of the data set, such as *community identity, urban identity, regional identity, national identity*, and *national and regional identities*. A distinction between the two aspects of place identity

[1]The (suggestive) scale of sense of place consists of: (0) not having any sense of place, (1) knowledge of being located in a place, (2) belonging to a place, (3) attachment to a place, (4) identifying with the place goals, (5) involvement in a place, (6) sacrifice for a place.

[2]Haartsen et al. (2000) argued that regional identities are not ("natural" or "objective") characteristics of this area, which is not completely consistent with Paasi's (1986, 2002c) view. Paasi believed that the "identity of a region" includes "objective scientific classifications" as well.

[3]http://project.carrot2.org/index.html

FIGURE 2 | A foam tree map indicating the major topics in place identity on the Internet. The visualization was generated by Carrot2 workbench based on 113 search results of place identity.

can be observed in the foam trees. Whereas topics such as *local identity*, *new identities*, *national identity*, *identity politics*, *identity of the area*, *importance of regional identity*, *role of regional identity*, *urban identity*, *development of regional identity*, *community identity*, *rural identities*, *place names*, and *regional specification* refer greatly to "place identity of a place," topics such as *role in identity*, *identity processes*, *identity development*, and *one's own place identity* have obvious connections to "people's place identity."

Category and Keyword Co-occurrence Networks

Analyses of category or keyword co-occurrence networks can offer a more rigorous and reliable representation of the literature on major topics of a domain (Chen et al., 2014a,b; Shi and Liu, 2019). Each publication in the WoS is assigned one or more subject categories and a number of keywords. Through analyzing the input records with CiteSpace, a total of 81 unique subject categories were found (see **Figure 4A**). The size of a node in **Figure 4A** indicates the citation frequency of a category. For example, the largest node in **Figure 4A** is GEOGRAPHY, with the largest citation count value of 142, which means 142 publications of the data set fit in the category of geography. The top 10 subject categories ranked by citation counts are geography (142), environmental sciences and ecology (91), sociology (90), social sciences (87), psychology (82), environmental studies (77), history (71), area studies (67), government and law (66), and political science (64). In a visualization of CiteSpace, a purple ring is used to represent the degree of a node's betweenness centrality. A node with high betweenness centrality indicates its important role of bridging the nodes it links. The top 10 subject categories ranked by betweenness centrality are psychology (0.30), sociology (0.28), environmental sciences and ecology (0.27), psychology—multidisciplinary (0.22), environmental studies (0.19), psychiatry (0.18), geography (0.16), genetics and heredity (0.14), education and educational research (0.13), and regional and urban planning (0.12). A total of 183 unique co-occurring keywords were found (see **Figure 4B**). The top 10 keywords ranked by citation counts are identity (109), place (82), place identity (71), space (68), regional identity (43), politics (41), attachment (41), geography (35), community (32), and place attachment (30). From the results in **Figure 4**, we can observe a general knowledge base that supports the research of place identity. As an interdisciplinary subject, place identity obtains its primary foundation in geographical sciences. Under the bridging efforts of psychology, sociology, and environmental sciences, it develops in other relevant domains, for example, government, political

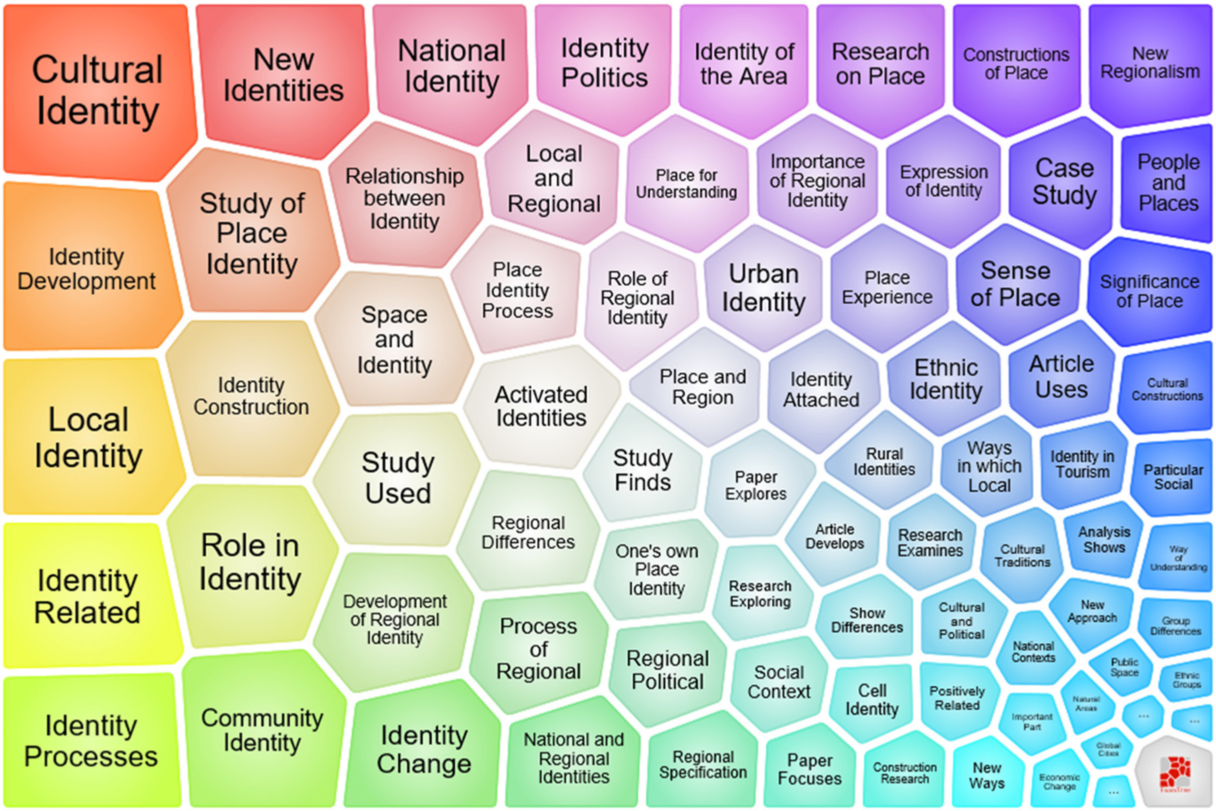

FIGURE 3 | A foam tree map generated by Carrot2, indicating the major topics in place identity based on 1,011 bibliographic records about place identity in the core database of Web of Science.

science, or spatial policy. It is worth noting that place attachment and place identity co-occur frequently as keywords, which indicates that there are considerable debates in the literature on their close and obscure relationship.

As shown in **Figure 4**, the research on place identity involves numerous disciplinary areas, which may shift over time. The burstness, signifying the fast shift of subject categories and keywords, indicates the most active research topics (Chen et al., 2014a,b). **Figure 5** shows the top 20 subject categories and keywords with the strongest citation bursts. The refined review results of the subject categories in **Figure 5** reveal the neurobiological supports for the phenomenological studies of human geography and environmental psychology on place identity (Lengen and Kistemann, 2012). At the top of the list of **Figure 5A**, the discipline of biology, including the subject categories of *biochemistry and molecular biology, neurosciences, neurosciences and neurology,* and *genetics and heredity,* occupied the hot area of place identity study prior to 2000. The decade after 2000 experienced an active exploration in plural disciplines in research on place identity, such as *history, computer science, geography, psychology, economics, cultural studies, planning,* and *education*. Gradually, the hot area came to the *humanities* and *social sciences* after 2010, while the subject category *social sciences—interdisciplinary* obtained the strongest burst strength of 5.5864 in 2013–2016. Recent hot areas were captured by *architecture*, *hospitality*, *leisure*, *sport*, and *tourism*, which suggests a shift of the study focus of place identity toward place products or place marketing. In general, the development of place identity research mainly experienced four stages, namely, theory construction and verification, active multidisciplinary exploration, in-depth study in social sciences, and application of place identity theory in place development.

Bursts of keywords may provide a more refined indication of hot topics (see **Figure 5B**). All of the top 20 keywords bursts appeared in the last 15 years. The keyword *attachment* has a strong burst from 2017 to 2019, with the maximum burst strength 3.6387, and it is used in 41 articles. It seems the keywords on the list can be classified into four groups. The first group focuses on places of various scales, including *home*, *neighborhood*, *city*, *nationalism*, and *world*. The second group focuses on personal characteristics, attitudes, and behaviors, including *race*, *gender*, *participation*, *experience*, and *attachment*. The third group focuses on the construction of place identity, including *construction*, *place-making*, *representation*, and *discourse*. The fourth group focuses on globalization and countermeasures, including *culture*, *authenticity*, *globalization*, *governance*, and *management*. The above preliminary classification implies that the research problems of place identity mainly revolve around *where* the place identity represents, *whose* place identity it is, *what* the place identity is, and *how* the place identity is affected.

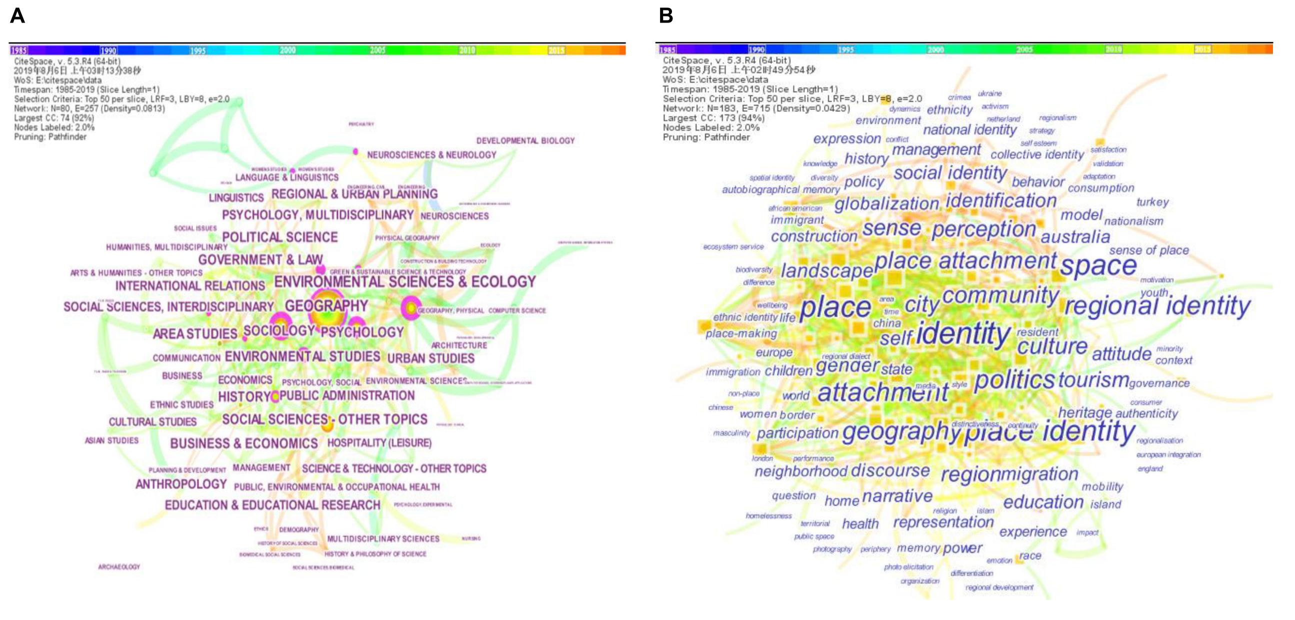

FIGURE 4 | Co-occurring subject categories network **(A)** and co-occurring keywords network **(B)**. The color of the network edge indicates the year in which the co-citation link was first made. For example, early co-citations are colored in blue, and the latest are in yellow and orange.

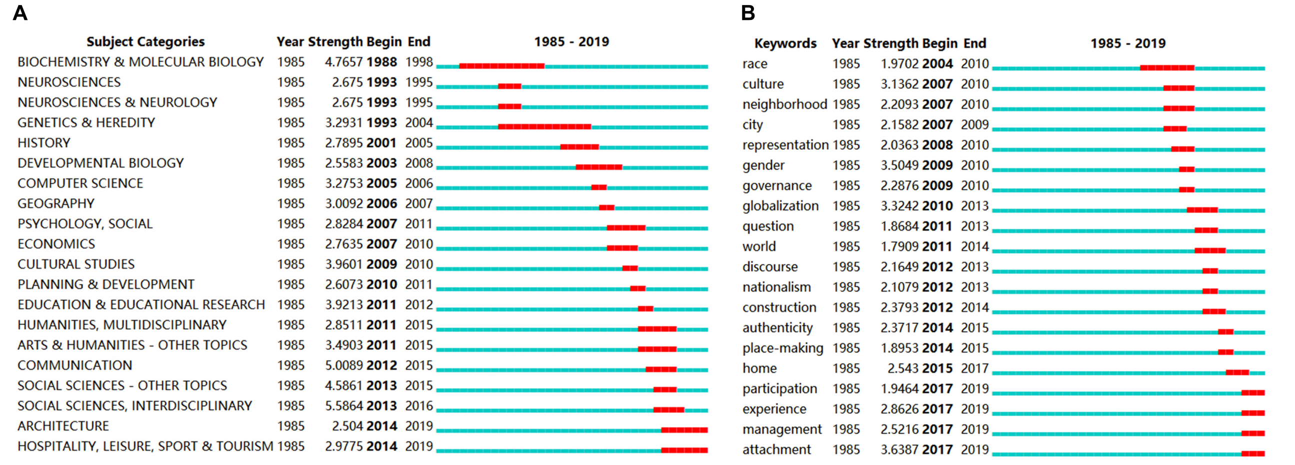

FIGURE 5 | Top 20 subject categories **(A)** and keywords **(B)** with the strongest bursts.

Clusters of Co-cited References

CiteSpace provides visualizations of synthesized networks of co-cited references, which are usually used for the analysis of emerging trends and new developments of a research field (Chen et al., 2014a,b). **Figure 6** shows a snapshot of the network of co-cited references derived from the core data set with CiteSpace. A link in the network represents how frequently two articles are cited together by other articles in the data set. A red ring in the network denotes a citation burst, while a purple ring represents the betweenness centrality. The size of a node of the network indicates the frequency of citations of an article. Based on their interconnectivity, these nodes can be aggregated into clusters that represent thematic concentrations. A cluster is a group of tightly coupled references that form the intellectual base of a research field, and articles citing these references represent the research front of that field (Chen et al., 2014a,b; Shi and Liu, 2019). The seven largest clusters numbered from 0 to 6 are shown in **Figure 6**. **Table 1** summarizes the basic information of the seven clusters. The label of each cluster is extracted with a log-likelihood ratio (LLR) test, and it summarizes the impact of the cluster on more recent research (Chen et al., 2014b). A silhouette value ranging from the lowest, -1, to the highest, 1, is used to measure the homogeneity of a cluster. Each of the silhouette scores in **Table 1** is close to 1, suggesting a reliable quality of grouping. Timeline visualizations generated by CiteSpace can make the new developments in research on

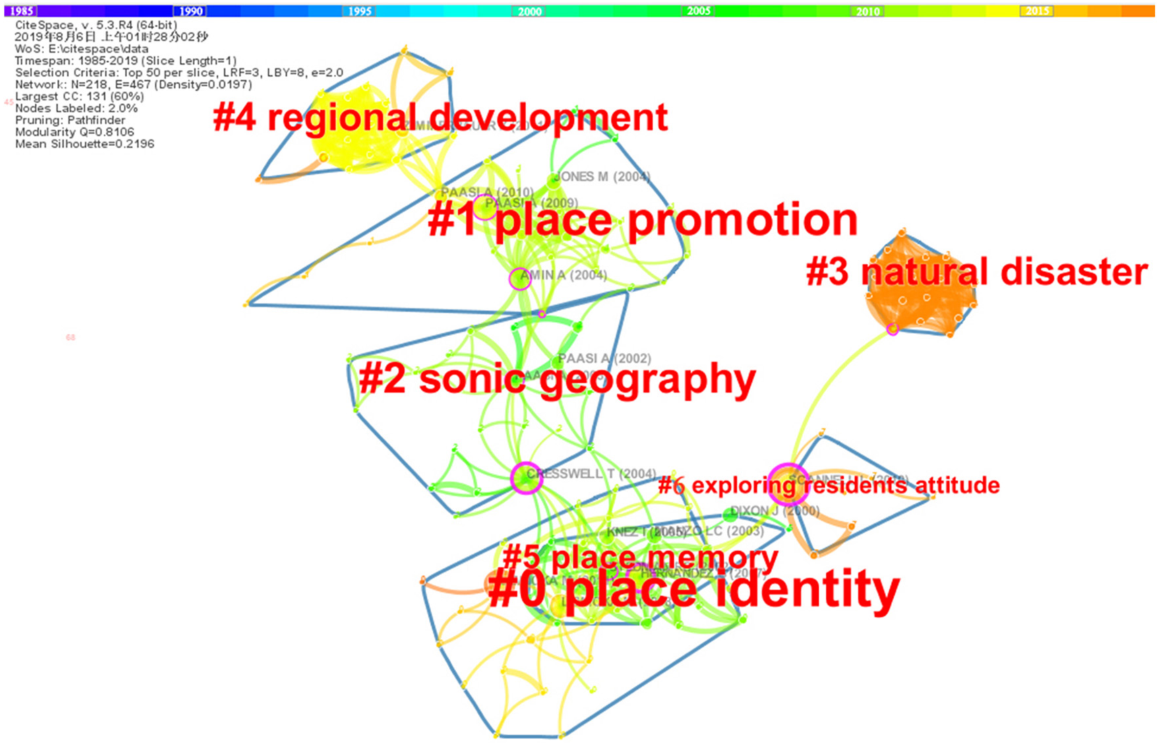

FIGURE 6 | A network of co-cited references based on citation instances made by the top 50 most-cited articles per year between 1985 and 2019.

place identity more easily recognized. As shown in **Figure 7**, the most recently emerging area is captured by cluster #3, labeled *natural disaster*, which can also be confirmed by the average year in **Table 1**, which indicates the average publishing year of the cited references of a cluster. Cluster #6 on *exploring residents' attitude* and cluster #4 on *regional development* are also relatively new.

Among these seven clusters, the largest one is cluster #0, labeled *place identity*, which contains 31 member references. Most of the top cited references in cluster #0 discussed place attachment, and some of them debated its relationship with place identity (Hernández et al., 2007; Lewicka, 2008, 2010, 2011; Rollero and Piccoli, 2010). Articles citing members of a cluster determine the aggregations of co-cited references, and they indicate major interests and research trends in a thematic field associated with the cluster (Chen et al., 2014a,b). **Table 2** shows the most-representative citing articles of the seven clusters. CiteSpace identified 11 citing articles shaping cluster #0. Evident thematic connections revolving around place identity can be observed from the titles of these citing articles. Particularly, these connections reveal the research concentration of cluster #0 on the role of place identity in social actors' attitudes and behaviors in the present transitional world with environmental depredation, climate change, urban renewal, and increasing and complex human needs, if we look further into the contents of these articles.

The second largest cluster, #1, shows thematic focus on the construction of place identity in the process of place promotion. The term "place promotion" appears in the title of a top citing article (Zimmerbauer, 2011). Place promotion and marketing are keystone practices in regional development, where political forces always play a determinant role. Deinstitutionalization or institutionalization of a region imposed by politics may lead to regional exclusion or othering when place promotion strategies are taken. Spatial identities are constructed by various stakeholders at different spatial scales. Place identity emanating from residents' perspectives has attracted a lot of attention in this theme, whereas its construction is still essentially impacted by the globalizing forces of development.

For cluster #2, the term "sonic geography" in the title of the top citing article (Boland, 2010) is extracted to be the group title. In the article, the influence of sound, for example, a distinctive accent and/or dialect, on the construction of local identity is examined. The cited references of cluster #2 concentrate highly on Paasi's articles (Paasi, 2002b,c, 2003), which results in the thematic focus of this cluster on the construction of place identity of regions. Research emphases of cluster #2 have been put on special factors shaping place identity, for instance, vernacular, symbols, narratives, children's reading and writing, and professionals involved in the development of a region.

The young cluster #3 focuses on the effects of physical environment (change) on place identity and well-being. Knez et al. (2018a) article titled "Before and After a Natural Disaster: Disruption in Emotion Component of Place-Identity and Wellbeing" gained much attention in this cluster. Studies on the role of place identity in regional development are prominent in

TABLE 1 | Largest clusters of co-cited references.

Cluster ID	Size	Silhouette	Average year	Label (log-likelihood ratio, *p*-value)
0	31	0.881	2008	Place identity (788.36, 1.0×10^{-4})
1	25	0.925	2007	Place promotion (473.96, 1.0×10^{-4})
2	21	0.884	2003	Sonic geography (483.58, 1.0×10^{-4})
3	17	0.994	2013	Natural disaster (397.53, 1.0×10^{-4})
4	17	0.963	2010	Regional development (609.67, 1.0×10^{-4})
5	13	0.952	2003	Place memory (352.53, 1.0×10^{-4})
6	7	0.988	2012	Exploring residents' attitude (125.06, 1.0×10^{-4})

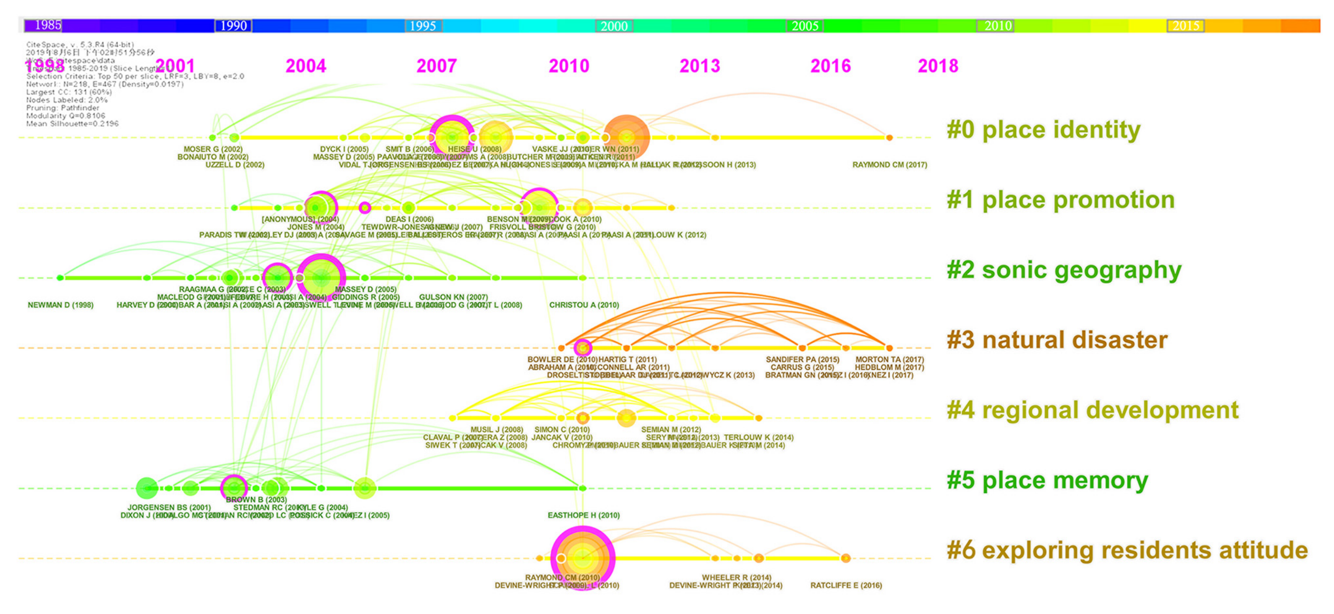

FIGURE 7 | A timeline visualization for the clusters between 1985 and 2019. New developments since 2010 are notably associated with cluster #3, #6, and #4.

cluster #4. Place identity may play a driver or a barrier to regional development. Graphic symbols, landscape features, discourses, rurality, and other place components can be employed as identity instruments for place marketing and local development. Yet, the mechanism underlying the role of place identity construction or reconstruction in regional development is under-discussed and needs more study efforts.

TABLE 2 | Articles that cite over 10% of members of each cluster.

Cluster ID	Coverage %	Citing articles
0	19	Fresque-Baxter and Armitage, 2012
0	19	Hernández et al., 2010
0	13	Vidal et al., 2013
1	16	Zimmerbauer, 2011
1	12	Vainikka, 2012
1	12	Zimmerbauer et al., 2012
2	24	Boland, 2010
2	19	Simon et al., 2010
3	24	Knez et al., 2018a
3	24	Knez et al., 2018b
4	53	Semian and Chromy, 2014
5	38	Lewicka, 2008
5	15	Chow and Healey, 2008
6	29	Bradley, 2017
6	29	Wheeler, 2015

Representative citing articles of cluster #5 suggest a thematic concentration on the effects of socio-spatial environment (change) on place identity. The term "place memory" for the cluster label appears in the title of a top citing article (Lewicka, 2008). The shaping of memory depends on many socio-spatial environment factors, such as history, culture, architecture, and family, which overlap the components shaping place identity. The transition or new development of a socio-spatial environment, for instance, undergraduates making the transition from home to university, can disrupt pre-existing memory and emotional attachments to a place and threaten place identity processes. The smallest cluster, #6, includes seven member references. Cluster #6 pays special attention to the relationship between place identity and residents' attitudes, especially the attitudes toward spatial planning or human intervention in places.

Apart from the difference in thematic concentrations, these seven clusters also differ in the foundation of the meaning of place identity upon which the citing articles are based. In

Table 2, representative citing articles of cluster #0, cluster #3, and cluster #5 conceive place identity as an individual's sub-identity. Those of cluster #1, cluster #2, and cluster #4 generally deem place identity as a social construct that differentiates a place from other places. However, place identity in the article by Zimmerbauer (2011) in cluster #1 is understood more in terms of regional consciousness and a sense of belonging to a region; a similar understanding can be found in the citing article by Miloslav (2018) in cluster #4. Some citing articles, for instance, Antonsich (2010) in cluster #2 and Semian and Chromy (2014) and Melnychuk and Gnatiuk (2018) in cluster #4, advocate the co-existence of the two intertwined and complementary meanings of place identity. The two representative citing articles of cluster #6 do not share the same view on the meaning of place identity. Wheeler (2015) adopted a similar meaning as that of cluster #1, cluster #2, or cluster #4. In the article by Bradley (2017), the meaning of place identity as a human's sub-identity seems mixed with that as features of a place. Though versatile meanings of place identity are used in different clusters or even in articles of a single cluster, they are not isolated and hence are sometimes intertwined in shaping the knowledge base of thematic concentrations. For example, Stedman's (2002) article titled "Toward a Social Psychology of Place: Predicting Behavior From Place-Based Cognitions, Attitude, and Identity," which has a betweenness centrality score of 0.11 and the most-cited frequency in cluster #5, is also co-cited in cluster #0 and cluster #2.

The extensive applications of place identity in various topics and the complex connections between its meanings in articles or thematic clusters have strengthened the necessity of in-depth examination on its fundamental meanings. Indeed, such necessity has already been responded to in the academic world, which is revealed by our citation burst analysis. A citation burst is a phenomenon where an article is highly cited at an increasingly faster rate. It indicates the likelihood that the scientific community has paid or is paying special attention toward the underlying contribution of these cited articles (Chen et al., 2014a,b). The top five cited references with the strongest citation bursts associated with **Figure 7** are listed in **Figure 8**, out of which Dixon and Durrheim (2000) is in cluster #5, Lewicka (2011) in cluster #0, Scannell and Gifford (2010) in cluster #6, Cresswell (2004) in cluster #2, and Amin (2004) in cluster #1. Dixon and Durrheim's (2000) article titled "Displacing Place-Identity: A Discursive Approach to Locating Self and Other," has the strongest citation burst, with a burst strength of 4.55. This article, published in *British Journal of Social Psychology*, presented a sympathetic but critical evaluation (review) of research on place identity. The beginning year of the citation burst of this article is 2006, which coincides with the time when the acceleration of publications on place identity took off (see **Figure 1**). The articles by Amin (2004) and by Cresswell (2004), both of which elaborated the concept of place, attracted great attention in studies on place identity from 2008 to 2012. The latest citation bursts are the remaining two review articles published in the *Journal of Environmental Psychology* by Scannell and Gifford (2010) and Lewicka (2011) on place attachment, in which its relation with place identity is discussed. From the evolvement of these top five busts, we can see that the fundamental meanings of place identity have been widely of concern in studies in this field. Articles focusing on reviewing or elucidating the meanings of place, place identity, and other place-related concepts have gotten critical attention. The attempts to fit together the versatile meanings of place identity have witnessed increasing difficulties, as the meanings of place, other place-based concepts, and their confusing interrelations have been developing.

MEASURING METHODS AND ROLES OF PLACE IDENTITY

Our scientometric survey has revealed the intellectual structure of the research landscape relevant to place identity. However, there are still some key issues about place identity research that this methodology seems unable to answer. For example, how has place identity been measured in the literature? What are the roles of place identity that have been identified? The method to measure or reveal place identity can be most scholars' primary concern when they propose questions in this domain. The roles of place identity in relation either to people or to regions have long been debated (see cluster #0, cluster #4), yet no universal agreement has been reached. In this section, we reviewed these two essential issues by further examining the contents of articles on place identity.

Measuring Place Identity

People's Place Identity

As a subjective and enigmatic social construct, place identity is seldom engaged in individuals' daily thoughts

FIGURE 8 | Top five references with the strongest citation bursts during 1985–2019. The red line segment indicates the beginning year and the ending year of the duration of the burst.

and communications. People do not become aware of place identity until their sense of place is threatened (Proshansky et al., 1983). Individuals' lack of self-awareness of place identity has not discouraged researches on place identity assessment. It is shown in plenty of articles that place identity can be measured either qualitatively or quantitatively.

As witnessed in the citing articles of cluster #3 and cluster #5, changes or interventions in living environment usually offer good opportunities for researchers to investigate the affected individuals' place identity. Chow and Healey (2008) interviewed 10 students twice over a 5-month period to assess the extent of changes in their place identities. These students had relocated from their homes to university. After the hurricane Hugo in September 1989, Hull et al. (1994) interviewed the residents of Charleston by telephone about the meanings associated with physical features damaged or lost due to Hugo. The authors argued that the meaning and values symbolized by place features or place icons play a role in the formation of place identity.

Rank ordering of place-related self-categorizations is widely used to assess place identity in many countries. The top citing article of cluster #5 (Lewicka, 2008) applied this instrument in a study on memory of residence places and its relationship with place identity and place attachment. Participants in the study were asked to rank three objects out of a list of possible places of identification, which include city district, city, region, country, Europe, the world, and finally, a human being.

A lot of studies rely on a Likert scale to assess individuals' place identity (Kyle et al., 2004; Williams and Roggenbuck, 1989; White et al., 2008). In many cases, these Likert-scaled items are measured on a five-point strongly agree to strongly disagree response scale. Typical items include "the place means a lot to me," "I am very attached to the place," "I identify strongly with this place," "I have a special connection to the place and the people who live and visit there," and so forth. In some studies, such items are measured with a seven-point scale. Carrus et al. (2005) measured regional identity with 16 items on a seven-point Likert scale. The authors divided the items into two categories, regional pride and regional empowerment. In a citing article in cluster #3 by Knez et al. (2018a,b), the 10 statements to measure place identity are also divided into two categories, namely, emotion and cognition components, and responded to by participants on a seven-point scale.

Some studies have made attempts to measure place identity with a single question. Pretty et al. (2003) asked for residents' responses to a statement to test their identification with their residential community. The statement was designed as, "I would really rather live in a different town. This one is not the place for me" (p. 275). The authors argued that "one's town is not the place 'for me' is to suggest that one's town is not constituted as part of one's self-identity" (p. 275). Respondents who agreed with the statement were classified into a group with low community identity. Those who disagreed were classified into a group with high community identity. The community identity of undecided respondents was deemed undecided.

Place Identity of a Place

Scholars tend to use "strong" or "weak" to depict the intensiveness of people's perception of the place identity of a certain area. In this sense, there can be a scale to measure the intensity of place identity. However, such a scale has not yet been unanimously agreed on in practice. Various methods have been adopted in literature to trace identities of places.

Approaches in literature to depict and measure place identity focus generally on what the identity is and how it is constructed by different social actors. Vainikka (2012), a representative citing article in cluster #1, used focus-group interviews to scrutinize to what extent place identities are shaped and shared by citizens. The author found that place identities perceived by citizens often differ from the identity discourses produced by media, regional administrations, and others. Haartsen et al. (2003) proposed a method to assess the rural identity perceived by residents of different age groups in the Netherlands. They asked the respondents to give the four words or phrases that first come to their minds when thinking about the countryside. The answers were aggregated into three categories: (1) a socio-economic functional image base ("how rural areas work"), (2) a visual–figurative image base ("what rural areas look like"), and (3) a socio-cultural image base ("what rural areas mean"). Elderly people were inclined to have a more socio-cultural representation of rurality, whereas younger people often characterized the countryside as an agricultural production zone. Similarly, place identity is divided into three interpretative dimensions, strategic, cultural, and functional, in the article by Van Houtum and Lagendijk (2001). This division was applied as a place identity analysis framework in two regions with comparable economic conditions and urban structures. The authors captioned each identity dimension of the two regions and elaborated with facts and historical narratives on how that identity was constructed.

As discussed previously about the thematic focus of cluster #2, extracting place identity components from texts, discourses, and narratives about an area is widely used by studies in this domain. Ritalahti (2008) searched and analyzed the web pages of individual tourism enterprises, municipalities, and other actors, in order to get a holistic view of how the identity of the study area is described there. The author did the same analysis in neighboring areas to detect possible boundaries created with place identities by social actors between these areas. Visitors' perceptions of the study area were then compared with the place identities ascribed by the tourism actors. Brace (1999) examined the identities of Cotswolds and the larger England in fictional and non-fictional rural writing, topographical writing, guidebooks, magazines, and articles. Other publicly available materials in relation to place identity, such as advertisements, were analyzed by researchers as well. Keegstra (2009) collected the pictures in advertisements on websites from different social actors in the Loire valley in France. The author identified different identities ascribed by different groups, including tourist organizations, farmer organizations, and governments.

Some research uses photos to measure how people perceive a place. This instrument is generally applied in two kinds of approaches. In the first approach, researchers take photos and present them to respondents (Van den Berg, 1999). Buijs et al. (2009) asked respondents to assess full-color pictures of 10 typical and non-urban Dutch landscapes to analyze the cultural differences in landscape perceptions in the Netherlands. Each picture was scored on a 10-point scale, ranging from 1 (not attractive at all) to 10 (extremely attractive). Hawthorne et al. (2008) applied a similar approach to examine residents' perceptions of land use in their neighborhood. The participants were asked to rank 19 pictures related to trail development and explain why they ranked them in that way, which was intended to understand the image of the neighborhood in residents' mind. In the second approach, researchers asked participants to take photos that they think can represent the identities of a place. Stewart et al. (2004) used this "photo-elicitation" method to map residents' visions of their community. Twenty participants took photographs of community landscapes and were interviewed while viewing their photographs. The interview texts about meanings of the environments were analyzed and grouped.

In addition to texts (discourse or narrative) and photos, other identity indicators, known as identity markers, are also explored extensively to reflect the distinctive identities of a place. Such identity markers include buildings, street symbols, landscape, cultural traditions, region names, dialects, dressing, and so forth, most of which can be found in the citing and cited articles of cluster #2, cluster #4, and cluster #6. Saleh (1998) argued that citizens recognize their places, to some extent, by the prominent traditional structures in the built environment. They examined the role of the various kinds of towers in constructing the identity of Saudi. Peterson (1988) noted that "people perceive places differently and differentiate between them by drawing on key physical features, cultural attributes, historical associations, experiential ties" (p. 451). He explored the place identity of Tucson and Albuquerque by analyzing thousands of commercial and non-commercial establishment names listed in the telephone directory. Nogué and Vicente (2004) suggested that landscape is the cultural projection of a society on a place and acts as a center of meaning and symbolism, and is a fundamental element in the constructing process of a territorial identity. They analyzed the role of landscape in the creation of national identity in Catalonia. Simon et al. (2010) argued that names of regions are essential symbols of place identities, and they connect the image of regions with people's regional consciousness. Social actors may try to improve the identity of a place by giving it a new name that can be associated with a positive image of the place. The authors traced and counted the names of regions in the Netherlands in the period 1950–2000 for an analysis of change in Dutch place identity. Wheeler (2015) investigated how wind farms are perceived by local residents as a reference to rural place identity.

Roles of Place Identity

People's Place Identity

People's place identity is individuals' strong emotional bonds to particular places or environments (Fresque-Baxter and Armitage, 2012; Zimmerbauer et al., 2012; Melnychuk and Gnatiuk, 2018). It influences the way we look, see, think, and feel in our interaction with the physical world. Proshansky et al. (1983) has been frequently cited in the clusters that concentrate on people's place identity, such as cluster #0, cluster #3, and cluster #5 (Chow and Healey, 2008; White et al., 2008; Devine-Wright, 2009; Devine-Wright and Clayton, 2010; Hernández et al., 2010; Fresque-Baxter and Armitage, 2012; Lengen and Kistemann, 2012; Urquhart and Acott, 2013). In this article, the authors initially depicted that place identity has five core functions: *recognition*, *meaning*, *expressive-requirement*, *mediating change*, and *anxiety and defense* function. The *recognition* function implies that individuals may adapt to and derive satisfaction from the settings where they spend a while. The *meaning* function proposes that place identity is the source of meaning for a given setting because of the cognitions that enable the person recognize a setting and understand its purposes. The *expressive-requirement* function involves two types of place identity cognitions, of which one is a cluster of cognitions that expresses the tastes and preferences of the person and the other represents what spaces and places require as far their purposes are concerned. The *mediating change* function indicates those place identity cognitions that serve to mediate change in discrepancies between a person's place identity and the characteristics of an immediate physical setting. The *anxiety and defense* function refers to those place identity cognitions that may signal threat or danger in physical settings or may represent response tendencies that defend or protect the person against these dangers.

There are many other efforts to explore the roles of place identity. For example, Fresque-Baxter and Armitage (2012), a representative citing article of cluster #0, summarized three conceptual approaches to analyze the role of place identity in climate change adaption. The first approach is the cognitive–behavioral approach, which examines how place identity influences individual decision making from risk perception to intention to action. The second one is the health and well-being approach, which emphasizes the importance of place identity in individuals' emotional, mental, and spiritual well-being. The third one is the collective action approach, which examines the role of place identity in shaping values at a collective level and opportunities for and/or barriers to collective action. However, within the literature, the functions of place identity articulated by Proshansky et al. (1983) or others are seldom systematically testified or refined in empirical studies. In some occasions, part of these functions may match or relate to the assumptions or conclusions of a few studies, either because these functions are defined inclusively or because they fit well with the real world.

Among empirical studies on place identity, most of them have demonstrated its positive effects, which include preventing negative environmental perceptions, providing support for public land use policies, strengthening the commitment of residents to improve their homes and neighborhoods, and so forth. By examining the effects of nationalism and local identity upon perception of beach pollution, Bonaiuto et al. (1996) found that identification with a town or nation prevents people's negative physical assessments of pollution, which is interpreted as a strategy used to cope with the threat by an outgroup to place identity. Low and Altman (1992) identified "satisfaction" as part of the merits of people's affective bonds with places because "places permit control, foster creativity and provide opportunities for privacy, security and serenity" (Chow and Healey, 2008). Kyle et al. (2003) found that when visitors' place identity increases, their support for paying fees for recreational use increases as well. Uzzell et al. (2002) argued that place identity can positively predict environmentally friendly conduct. Brown et al. (2003) found that the commitment of neighbors to improve their own home and the whole neighborhood is positively related to the emotional connection they have developed to the place. Carrus et al. (2005) also detected a positive role of place identity in predicting support for the protection of nature areas. Manzo and Perkins (2006) argued that particular preferences, perceptions, and emotional connections to places relate to community social cohesion, organized participation, and community development. Hernández et al. (2010) found that place identity positively influences environmental attitude and injunctive social norms. Knez et al. (2018b) found a positive relationship between place identity and perception of naturalness.

A few articles have also pointed out that the strong emotional bonds between individuals and particular places may have a less positive role. As place identity is a dynamic and dialectic process, in some occasions, it may act as resistance factors that are latent in man's mind. Manzo and Perkins (2006) argued that if people's emotional responses to a place are not acknowledged and understood, they can be divided and immobilized by their anxieties. Forester (1987) pointed out that bonds with a place can form the basis for cooperation and community action, and they can also lie at the root of community conflict. Both Stoll-Kleemann (2001) and Bonaiuto et al. (2002) suggested that local residents would oppose the designation of protected nature areas if a strong sense of identification with their local community is present.

Place Identity of a Place

It is widely accepted and also revealed in cluster #4 and cluster #1 that place identity is closely related with regional development. Paasi (2009b) argued that a strong place identity is a remarkable resource in regional development. Place identity is the image inhabitants hold of the home area, and the embodiment of such an image in regional development activities encourages people's creativity and entrepreneurship. Semian and Chromy (2014), the top citing article of cluster #4, shared Paasi's conceptualization of place identity and argued that place identity can play a positive or negative role in regional development. Terluin (2003) did not mention place identity as a determinant of leading and lagging EU regions, but she believed that strong and leading actors' capacity is vital for regional development in building a strong place identity, which can facilitate the mobilizing of the self-help capacity, foster co-operation, and help turn handicaps into development assets. Taking EU as an illustrative case, Paasi (2009b) pointed out that the emotional aspects of civil society are increasingly recognized in the cohesion policy of the EU, and place identity has become an instrument for promoting regional development. The role of place identity as a tool to promote regional cooperation and possibly regional integration has been witnessed in East Asian as well (Terada, 2003). However, place identity is broadly considered as an inherently imprecise and fuzzy notion, and the mechanism about how place identity affects regional development is laden with social and productive magic (Hurrell, 1995; Paasi, 2003). Though social actors' commitment to enhancing place identity, and subsequently, regional development, is widely acknowledged, the principles behind such contribution have seldom been proven (Terluin, 2003). There is a long way ahead for scholars to identify how and to what extent place identity can promote regional growth.

Numerous studies on place identity have stressed its intrinsic nature of resistance to globalization in the process of regional development, which responds to our previous keyword burst analysis, where globalization and countermeasures are highlighted as hot topics (Paasi, 2002c, 2003; Van Rekom and Go, 2006). Globalization can be defined as the intensification of economic, political, social, and cultural relations across borders, while regionalization is the growth of societal integration within the border of a given region (Kacowicz, 1999). A region is established in the regionalization process, maturing with people's consciousness of place identity that differentiates it from others. While increasingly fast globalization is threatening the genuineness of regions, place identities stand to maintain regional distinctiveness. This plausible contention can be greatly found in research about tourism and place identity. Dredge and Jenkins (2003) argued that globalizing forces have contributed to increased homogenization of tourism products. Local destination identity has been associated with perceptions of homogeneity. Destinations are under increasing pressure to construct and promote distinct identities in order to counterbalance these homogenizing influences and pursue tourism growth. Gospodini (2004) suggested that built heritage and innovative design may work as place identity generators in modern and post-modern European urban societies. They can promote tourism and create social solidarity among inhabitants, and subsequently defend against the place identity crisis in the processes of economic and cultural globalization. While the preservation of place identity can attract tourists, it puts the place at a risk of exposure to globalization forces. However, economic success brought by tourism may stimulate the place to maintain its identities that are discovered by tourists (Van Rekom and Go, 2006).

Besides the role in maintaining a place, place identity has also become a slogan for making a place, which is also referred to in our previous keyword burst analysis (Paasi, 2009b). For one, an established place identity shared by common social stakeholders forms structures of expectations, which can be used as a collective mobilizing force (Terluin, 2003; Knapp, 2006). For another, discourses on place identity, which embody social actors' interests and expectations, may create the reality that they are describing and generate action when the reality is accepted by the public (Paasi, 2002a). Politicians and policy makers have been, for a long time, exploiting place identity narratives in planning to lead place-making (Paasi, 2009b). Saleh (1998) argued that place identity is an important factor to mobilize people, which explains planners' enthusiasm for its introduction and application. Stewart et al. (2004) suggested that place identity has the potential to serve as visions for planning processes. The involvement of citizens' thoughts on what the identity of a place is and should be forms part of the visioning process in planning. Hague and Jenkins (2005, p. 8) deemed planning to be about place-making, which means one of the significant objects of planning is to "create, reproduce or mold the identities of places through manipulation of the activities, feelings, meanings and fabric that combine into place identity," Moreover, place-making needs planners to incorporate visions of place identity not only from politicians' and economic interests but also from local residents and other members of civil society, because identities ascribed to a place by different stakeholders are contested and may play a potential role in social conflicts (Bridger, 1996; Haartsen et al., 2000; Stewart et al., 2004).

DISCUSSION

Place identity is gradually preferred by geographers to preach in extensive occasions, such as planning, regional regeneration, heritage conservation, landscape appreciation, tourism, environmental management, environmental behavior, local conflict, and so on. Researchers involve place identity in so many diverse contexts that this term is endowed with increasing explanations and connotations. The broad use of place identity makes it like a panacea to deal with problems of the relationship between a place and people. Although the meanings of place identity have not been unanimously agreed upon to date, it is undoubtedly positive that "place identity" has acted as an outlet to integrate physical reality and social cognition. When we begin to become aware of the complexity and chaos in place management issues, the object-oriented strategy-making process fades out of its dominant popularity in place-making. As a traditional top–down policy-making approach tends to meet resistance in the late policy implementation phase, increasing attention has been paid to information and knowledge from the grassroots and stakeholders. Participatory planning has been introduced, and a great deal of consultancy work is launched before decision making. To do that, we aim at digging about what and how people think of the place where they live or that they care about. People's perception of a place derives from direct or indirect contact with the place. They ascribe identities to a place based not only on objective physical features but also on less tangible meanings, memories, and information from others, from the past and the future.

One of the essential prerequisites to make a place is to cater to its owners' or users' thoughts and requests. The rising of inhabitants' versatile requests on places drives us to contemplate place management issues as an integration of complexity. We want to modernize our place with global leading technologies, yet we are afraid of losing its historical traces. We need wide roads to improve traffic and larger cities to accommodate more population and buildings, yet we are reluctant to sacrifice limited farmland and natural landscape, which preserve rural identity. Such dilemmas or conflicts in place development are realities, and we cannot tackle them within a single sector or discipline. Place identity can be a solution to integrate those issues (Pinto, 2000). However, when we come to this approach, we may encounter another risk. Since the components of place identity are too broad and inclusive to operate, pursuers of place identity are sometimes frustrated by its vague meaning. In a lot of studies, researchers try to avoid in-depth debate on the conception of place identity when they investigate identities of a case area. Instead, they lean on previous relevant studies and extend those definitions and methodologies in their own ways.

People's place identity and the place identity of a place overlap but are not the same. Both constructs embody subjective or emotional bonds between man and the physical world. People's place identity is part of individuals' personalities related to places that are significant in the formation of their identities. Place identity of a place is the personality of the place. Such personality is, in most occasions, ascribed by people to the place where they live or that they care about. As shown in **Figure 9**, through people's interaction with a place, the place influences and subsequently constitutes people's social (collective) and personal (individual) identity (Nario-Redmond et al., 2004). Meanwhile, people perceive and construct the identity of a place. Although the identity of a place is reflected through people's consciousness, which is generated mostly by man's nervous system, it originates from the physical, symbolic, institutional, and other components of the place (Raagmaa, 2002). Any changes in these components, deduced either by external forces (e.g., natural disaster, spatial planning, globalization) or internal growth (e.g., regional development or promotion) would impact the identity of a place and its inhabitants' place identities. As the interaction between people and a place is a mutual, dynamic, and eternal process, the creating and fostering of place identity is also a mutual, dynamic, and circular process (see **Figure 9**) (Ramos et al., 2016).

Generally, the efforts to promote the identity of a place can enhance its inhabitants' place identities at the same time, and vice versa. The intricate relationships between people, place, and place identity occasionally confuse researchers who try to deconstruct the meanings of place identity. For example, Yuen (2005) cited Proshanky's definition to conceive place identity as a "substructure of self-identity." However, most of the arguments in his article concentrate on the increasing emphasis that Singapore has given to urban conservation as a way to strengthen the identity of the city. Paasi's theory on the formation of a region and its identity is applied in the research by Raagmaa (2002). The measurement of place identity Raagmaa designed is biased to examine residents' identification with their communities. We need place identity as a term to integrate complex physical reality and social cognition, but we do not expect a vague meaning of this term to be widespread in various domains.

Place identity is more than spatial consciousness. Place identity is claimed as a social construction based on physical reality, but we cannot overlook the objective components and qualities of places and people, which also form part of their

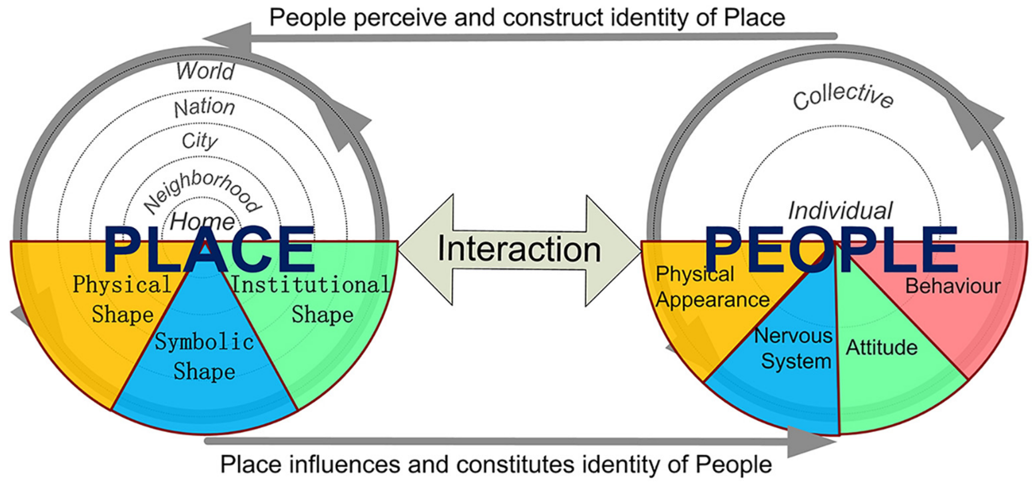

FIGURE 9 | Relationships between people, place, and place identity.

identities. We can easily tell a mountain from a lake not because we ascribe high altitude to the mountain or water to the lake but because of the reality that a mountain is high and a lake has water. To explain the meanings of place identity, Paasi (2002c, p.38) draws a diagram showing the connections of the dimensions of place identity. Inspired by Paasi's work, the social and personal identity theories, and other attempts to identify contents and dimensions of place-related identity (Nario-Redmond et al., 2004; Stobbelaar and Pedrol, 2011; Ramos et al., 2016), we summarized four major dimensions of the meanings of place identity (see **Figure 10**).

To study people's place identity or the place identity of a place, the literature generally analyzes them through two perspectives: external looks or internal thoughts. From external looks, researchers observe people's physical appearances and behaviors associated with a place. How a group of people looks and behaves is thought to be a direct indicator separating this group from others. People's dress, hair, skin, dialect, diet, and other behaviors are inherited to a great extent. In other words, these characteristics lean on local traditions and genetic inheritance, which have roots in a place. People who have migrated to a new place would keep these origins for a long time. Therefore, the external looks of these characteristics constitute part of people's public self-identity imprinted by the place where they or their ancestors come from.

As to the external looks of a place, we tend to locate the place on a map at the very beginning. The boundary on the map offers a concrete geographic position and extension of the place for people to identify it in the world. Other tangible elements of a place, such as place names, buildings, land use, population, landscape, landmarks, governments, culture, organizations, and so on, define the external looks of this place together. According to Paasi's (1986) view on the formation of a region, these elements can be generally grouped into three categories, which are known as physical shape, symbolic shape, and institutional shape. In instructions of a place, one or more of these tangible elements are usually narrated as components that make up the identities of that place.

From the perspective of internal thoughts, researchers strive to design methods to explore subjective connections between people and places. When scientists carry out empirical studies from this view, there is a subtle difference between the methods to measure people's place identity and the place identity of a place. Respondents are usually asked how they perceive a given place or places in both cases. However, in the case of studying people's place identity, researchers' aim emphasizes especially on the meanings and importance of the place(s) people feel in their lives. To attain that, investigations revolve mainly around questions about people's attitudes and feelings related to a place. Such attitudes are usually value-oriented, such as love for a country, and landscape preferences, which indicate the role of a place in the formation of a belief or standards that guide people's choices. The feelings can be considered as affect-oriented, which indicates the internalized manifestations of the effects of a place (or elements of a place), such as the importance of elements of a place to the self, and the identification with places of different spatial scales. It is necessary to point out that people living outside of a place are seldom included in this case, because those who have no contacts with the place can hardly perceive the importance of the place in shaping their personality. People's internal thoughts that reveal their bonds with a place constitute part of their private self-identity imprinted by the place.

With respect to internal thoughts about the place identity of a place, researchers' major efforts focus on the images of a place people hold in their minds. Such images can be perceived by people living either inside or outside of a place (Paasi, 1986, 2002c). In academic studies and spatial policy-making practices, both collective and individual perceptions of place identities have been paid much attention. Individuals seldom encounter official boundary lines or marks of places in daily life. They often perceive the existence and extent of a place in mind according to the elements of the external looks of the place. From this point,

	External looks	Internal thoughts
People	Physical appearance (*e.g., dress, hair, skin*); Behavior (*e.g., dialect, diet, traditional practice, skill*)	Attitude (*e.g., patriot, goal, preference*); Feeling (*e.g., importance of elements of a place to self, identification with places of different spatial scales*)
Place	Physical shape (*e.g., territory, landscape, building, land use*); Symbolic shape (*e.g., landmark, dialect, name of the place, boundary on the map*); Institutional shape (*e.g., government, firm, neighbourhood*)	Individual perception (*e.g., place boundary in mind, representative elements of a place in mind, holistic image of a place*); Collective perception (*e.g., place marketing, discourse about a place*)

FIGURE 10 | Quadrantal dimensions of the meanings of place identity.

researchers examine the boundary of a place in individuals' minds to study the intensity of the perceptions of place identity. Besides, individuals bear in mind different representative elements and holistic images of a place, which forms the competitive nature of place identities and becomes the central research interest in this domain. The elements and images of a place in leading social actors' minds are always shown in place marketing or planning media, discourses, and narratives, with the intention to present to the world what the identity of the place is. In some occasions, the place identity constructed by leading social actors may not be consistent with the place identity perceived by the public, but it may be gradually accepted as the collective place identity through spatial planning, place development, or promotion.

CONCLUSION

On the base of the bibliographic records in the core data set of Web of Science related to place identity, this paper identified active research topics and new developments in place identity with a scientometric analysis. An extended survey on measuring methods and roles of place identity in the contents of academic articles was done to supplement the scientometric approach. Distinctions and interrelations between the two meanings of place identity were highlighted with respect to intellectual base, thematic concentration, measurement, and function. Although this paper tried to separate place identity of a place and people's place identity in multi respects, there are a lot of subtle similarities between their attributes. Both of them are contested, and both are attached with significance in place development, planning, and social conflicts. Similarities also exit in the methods to study them. The establishment or intensity of the identity of a place is often examined by asking about people's identification with the place. Such similarities could be greater if additional efforts are made to look into the cross-cited articles between the clusters generated by our scientometric analysis. Longtime ignorance of the mixed uses of the two meanings in the literature, in addition to their confusing relationships with other environmental psychological concepts, such as place attachment, has led to a lot of criticism, which can also be blamed for the slow progress in the development of place identity theory.

The quadrantal dimensions of the meanings of place identity presented in this paper are expected to help scholars find their positions when they are involved in research questions in this domain. Place and people are interdependent. Although people's place identity and place identity of a place are not the same, we did not mean to stress their differences and encourage separated studies on either of them. Instead, places, people, and processes through which both identities are formed should be taken in a comprehensive structure that is supported by a set of theory-grounded principles (Lewicka, 2011). The existing theories relevant to place identity, as well as their interrelations, within the top subject categories identified by our scientometric analysis are not reviewed in this paper, but they are worthy of future study.

To make places better in the contemporary world with increasing mobility and globalization, place identity has been gradually used as an instrument in various domains, such as spatial planning, place marketing, and so forth. However, there are still many outstanding key issues in this area. What should be and how to establish the optimal identity of a specific place? How to reconcile the optimal identity of a place with residents' and other stakeholders' place identities? How to measure the costs and benefits in terms of social capital, regional or community resilience, and other human well-being or place growth-related scales, of the transitional process of place identity? More empirical studies are needed to figure out practical solutions and principles for these issues. Otherwise, the research of place identity will always float in the air, so that policy makers and relevant practitioners are not able to touch and operate this tool in practice. Before answering the above questions, we suggest the most fundamental task at present should be to straighten out the differences between place identity and other concepts defining people's emotional bonds with places and to sort out the basic framework of place identity theory and its relationship with other relevant theories.

AUTHOR CONTRIBUTIONS

JP collected and analyzed the data in the manuscript. JP wrote the manuscript. DS introduced the idea and guided the revision of the manuscript. QW offered suggestions for the revision of the manuscript.

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Exploring the Construct of Relational Values: An Empirical Approach

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In recent environmental research, relational values (RVs) have emerged as a new group of values to explain environmental behavior. Although this new concept is attracting attention, empirical studies on the subject are still rare. On this basis, we have conducted three studies to analyze an existing measurement tool for RVs and compared the construct with the concept of connection to nature. In study 1, we confirmed convergent and discriminant validity of the RV scale by comparing it with the Two Factor Model of Environmental Values (2-MEV) model using a sample of n = 350 university students. Additionally, study 1 verified reliability using test–retest reliability on three different groups of students (n_1 = 53; n_2 = 37; n_3 = 48). In study 2, principal component analyses were performed to examine the structure of RVs and to compare it to the concept of connection to nature by reusing the sample 350 university students from study 1. The results show that RVs and connection to nature are not fundamentally distinct constructs, but overlap. However, if the structure of the RV measurement is forced to a single factor, no perfect fit is found, making a multidimensional solution more likely. A third study was conducted to review the results from study 2 using confirmatory factor analysis on a new sample of 878 university and high school students. Study 3 confirmed RVs as a multidimensional construct with three factors: care, community, and connection. It also proved the overlap of the connection to nature and RV concepts to some extent.

Keywords: relational values, connectedness to nature, connectedness to nature scale, scale validation, environmental behavior, two factor model of environmental values model

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INTRODUCTION

Why should nature be preserved and protected? This question is often answered from an instrumental or an intrinsic position (Tallis and Lubchenco, 2014). The fundamental postulate of the intrinsic perspective is that biological diversity has a value of its own, regardless of the potential use or benefit for humans. Species have value because of their pure existence, and this value is seen as inviolable (Soulé, 1985; Sandler, 2012). In terms of the instrumental point of view, the focus is on ecosystem services for the protection of nature. Instrumentalists argue that this beneficial approach is more effective than an intrinsic value of nature (Reid et al., 2006). Furthermore, protection of nature for its own good is considered as outdated and impractical (Soulé, 2013). A weakness of the instrumental view is the existence of natural things that have little or no value to humans. For this reason, intrinsic values should not be disregarded. However, instrumental arguments are more often effective for the general public and should therefore be used in contexts where conservation is crucial (Tallis and Lubchenco, 2014).

As a rule, human decisions are not only based on intrinsic values or the usability of nature. Hence, a third group of values explaining environmental behavior has recently gained attention: relational values (RVs). This original philosophical term includes human beliefs on what is the right and appropriate way to deal with nature. RVs reflect the responsibility and relationship humans have toward nature and the place where they live. In addition, RVs give rise to questions regarding how to deal with nature and the land to live a good and meaningful life. But RVs include not only the relationships of humans with nature and the responsibility associated with them but also the relationships and decisions between people involving nature. In this way, RVs are involving the human collective as well as the individual. Natural objects do not contain RV *per se*, but RVs are the results of the relationship or commitment to them (Chan et al., 2016).

RVs are not an end in itself but provide important factors for environmental conservation, sustainability, and living a meaningful life (Himes and Muraca, 2018). The practical use of RVs can be explained by the example of protected areas. Without RVs, protected areas have to justify their existence in an instrumental or intrinsic way. This means that those areas either have to provide some kind of benefit for humans, most of the time valued in ecosystem services, or are valued "just" for their own sake. RVs add a third option, namely, to appreciate nature because of the people's relationship to it and the responsibility toward other people (De Vos et al., 2018).

In the last years, a number of articles on the topic of RVs have been published (e.g. Chan et al., 2016; Arias-Arévalo et al., 2017; Chapman, 2017; Klain et al., 2017; Chan et al., 2018) that helped to achieve a better understanding of the RV concept and displayed the strength and relevance of RVs to a wide range of scientists in different research fields. For example, Ishihara (2018) made a noteworthy contribution to the topic of RVs from the sociology perspective. She integrated RVs in the concept of Pierre Bourdieu's habitus. RVs can be seen as a part of this habitus that is expressed by culture and the social group an individual is part of. Beyond that, RVs also have a great influence from the social perspective, and the violation of these values has a strong impact on the affected community. If, for example, an important place for the community is destroyed, it could also lead to the loss of relationships between humans and nature (Grubert, 2018). This is a critical difference to the instrumental values. When a habitat is destroyed, from an instrumental view, it can be relocated to another place and still provide the same ecosystem services than before. For RVs, it is different. The bond and emotions connected to a place cannot be relocated (Grubert, 2018). This context clearly demonstrates the importance of RVs, although they are criticized for not being a useful categorization by some researchers (Maier and Feest, 2016).

In addition, the connection of RVs and the conservation of biodiversity on agricultural land has to be mentioned. Large tracks of land, locally and globally, are used for agricultural purposes. The cultural RVs help to sustain biodiversity and particularly the species diversity in these areas. When politics focus on instrumental values and economically orientated decisions, less actions in conservation will be taken (Allen et al., 2018). Hence, RVs may be a crucial tool to influence politics to reach a more sustainable use of nature by addressing a broad spectrum of people: stakeholders, scientists, local community, managers, and politicians (Stenseke, 2018).

Even if RVs get a lot of attention in review articles and qualitative analysis, there is a lack of quantitative research on this topic. Britto dos Santos and Gould (2018) argue that environmental education has already approached RVs without defining them as such. For the authors, connectedness, care, community, identity, kinship, responsibility, and stewardship are all part of RVs.

In psychology, there are various approaches that try to integrate the concept of values into a theoretical framework. Values are defined as ideas or beliefs regarding desirable goals or behavior. They go beyond certain situations, help to evaluate behavior or events, and can be ranked according to their importance (Schwartz and Bilsky, 1987). The concept of values clearly differs from the concept of attitudes, which expresses a positive or negative tendency toward an entity (Eagly and Chaiken, 1993). The fundamental difference between values and attitudes is the generality and the hierarchical order of importance of values (Schwartz, 1992). Values are broader than attitudes and therefore serve as an organizational system for attitudes and beliefs (Schultz et al., 2004). Attitudes have a certain influence on behavior, even if they cannot be translated one-to-one into behavior (Inglehart, 1997; Hitlin and Piliavin, 2004). Beliefs are personal conceptions, which assign a truth content to a fact. In contrast to values, beliefs are not guiding principles in life but allow a quick personal assessment of the plausibility of situations and contexts (Schwartz, 2012). Values and beliefs are important basic components of personal identity (Hitlin, 2003) and thus as a way to organize information about oneself (Clayton, 2003).

The construct of RVs seems to overlap with existing validated environmental psychological constructs, for example, with the theory of basic human values developed by Schwartz (1992). The author identified 10 universal values that display the essential basic needs of humans. These 10 values can be organized in four higher ordered factors: openness to change, self-transcendence, conservation, and self-enhancement. Especially the factor self-transcendence that includes benevolence and universalism seems to overlap with RVs. The goal of benevolence is to preserve and enhance the welfare of the community a person is in contact with, while universalism aims to understand, appreciate, tolerate, and protect the welfare of nature and all humans (Schwartz, 2012). The combination of nature and society is a factor that occurs in both concepts.

In addition, the concept of Stern and Dietz (1994) has some similarities with RVs. They explain environmental concerns through three kinds of values: egoistic, altruistic, and biospheric values. Egoistic values focus on parts of the environment that effect a person directly. If environmental changes adversely affect people, the person concerned should act in a more environmentally friendly way to avoid the consequences. The altruistic values describe the moral responsibility not to harm other people, while the biospheric values account the cost and benefits for an ecosystem or the biosphere (Stern and Dietz, 1994). The three values influence the personal beliefs and norms and in this way cause proenvironmental behavior (Stern, 2000). A proenvironmental decision can be motivated by all three kinds of values. For example, buying a smaller and energy efficient car can be motivated because it is cheaper (egoistic values), because it produces smaller amounts of toxic gases that could endanger the health of other people (altruistic values), or because it produces less carbon dioxide (CO_2) to protect the environment (biosphere values) (De Groot and Steg, 2010). Once again, RVs overlap with a known concept of environmental psychology. Both constructs involve a personal relation to nature but also the decisions and relationships that involve other people.

Another important concept that has to be mentioned in this context is connection to nature. Connection to nature is a well-known construct in environmental education research and environmental psychology and shows a certain resemblance to RVs.

Although connection to nature receives so much attention, there is no clear and universal definition. Some authors particularly emphasize the emotional focus of the concept (e.g. Mayer and Frantz, 2004; Nisbet et al., 2009), while others consider, for example, the role of nature in personal identity (Clayton, 2003). For our research, we would like to draw on the conceptual statements of Schultz (2002), who describes the connection to nature as the belief in how strongly a person sees himself or herself as part of the natural environment. Schultz (2002, p. 67) defined connection with nature as "*[. . .] the extent to which an individual includes nature within his/her [.] self*." He describes his concept of inclusion with nature with three core dimensions. The cognitive component describes the feeling to be integrated in nature, and the affective component includes the care for nature, place, and animals. The third component is behavioral. When people are connected to and care for nature, they are more motivated to act in the interest of nature (Schultz, 2002).

Environmental psychologists developed a number of measurement tools for natural connectedness: These include the Nature Relatedness Scale by Nisbet et al. (2009), the Environmental Identity (EID) Scale by Clayton (2003), the Connectedness to Nature Scale (CNS) by Mayer and Frantz (2004), the Inclusion of Nature in Self (INS) Scale by Schultz (2002), and the Implicit Association with Nature Scale by Schultz et al. (2004). Most of the mentioned concepts show intercorrelation and can therefore be considered as a single construct (Tam, 2013). Some authors have demonstrated that the concept of connectedness to nature can be taken more widely and is related to environmental values or identity (Brügger et al., 2011; Olivos and Aragonés, 2011). On the basis of the abovementioned research, it can be concluded that RVs as well as the concept of connection to nature contain the personal relationship to nature. In addition, the connection and care of places have important roles in both constructs.

Connection to nature has gained a lot of attention in environmental psychology as well as in interdisciplinary research. The different measurement tools for connection to nature are widely used to evaluate environmental education programs and explain proenvironmental behavior (Kals et al., 1999; Frantz et al., 2005; Kaiser et al., 2008). In most modern western societies, adults and children spend more time indoors and less time in natural environments. This development obviously has a negative effect on the connectedness to nature. Children who are spending more time playing indoors, watching TV, or playing video games have a lower implicit connectedness to nature (Bruni and Schultz, 2010). Children develop connection to nature through positive nature experiences and the time spent in nature as a child is an important predictor for the time spent outside later in life (Rosa et al., 2018). On the other hand, time spent outdoors leads to increased connection with nature (Schultz and Tabanico, 2007; Kaiser et al., 2008; Andrejewski et al., 2011; Dornhoff et al., 2019).

Why is the decrease of affinity to nature a problem? Various studies are dealing intensively with the relationship between connection to nature and proenvironmental behavior. People with a stronger connection to nature show more protective behavior compared to people with lower connection (e.g. Kals et al., 1999; Frantz et al., 2005). Furthermore, a higher connection supports environmental attitudes and more motivation to preserve nature (Wells and Lekies, 2006; Kaiser et al., 2008). In summary, people with a closer connection to nature tend to be more environmentally friendly (Clayton, 2003) and show an increase in proenvironmental behaviors (Geng et al., 2015). Additionally, a higher connection to nature leads to higher vitality, lower mental distress, and higher psychological well-being (Cervinka et al., 2011; White et al., 2013; Capaldi et al., 2014).

While there are many studies examining connection to nature and the effect on proenvironmental behavior with empirical data by now, recently, only two studies with a quantitative approach to examine RVs have been published (Arias-Arévalo et al., 2017; Klain et al., 2017). One reason could be the lack of a validated measurement instrument for RVs. An extension to more quantitative research on RVs could provide solid empirical evidence and confirm the relevance of RVs in environmental research and conservation. Additionally, global aspects of RVs could be identified by checking for commonalities or differences in different cultures or countries to promote conversation and collaboration between these groups. Finally, statistically, representative surveys can reflect the public view and therefore help politics to make environmentally beneficial decisions (Schultz and Martin-Ortega, 2018).

A fundamental problem in the empirical research context on RVs is the lack of an established test instrument that has been checked for its test quality criteria. In study 1, we want to close this gap and verify the validity and reliability of an RV measurement tool developed and used by Klain et al. (2017). This necessary step is important for the development and establishment of a reliable and valid measuring instrument with which the construct can be examined in more detail. To confirm validity and reliability, the RV instrument was compared to the Two Factor Model of Environmental Values (2-MEV) model. The 2-MEV model was chosen because it is of great importance in environmental research, and its quality and structure have often been successfully confirmed (e.g. Milfont and Duckitt, 2004; Johnson and Manoli, 2010; Boeve-de Pauw and Van Petegem, 2011). Since there is also a gap in empirical research on the structure of the RVs, we used the RV measurement instrument (after both discriminant and convergent validity and the test–retest reliability were confirmed in study 1) to empirically investigate the structure of the RV construct (studies 2 and 3). In the first step (study 2), a structure-discovering method [principal component analysis (PCA)] was selected to obtain a basic overview of the factor structure of RVs. In order to further refine the results of study 2, the structure was then examined in study 3 with a new sample using structure-checking methods [confirmatory factor analysis (CFAs)]. Since connection to nature is very important in the context of environmental education and environmental psychology, and since we found some theoretical similarities between the concept and RVs, we additionally investigated the structural relationship between the RV items and connection to nature in studies 2 and 3. For this purpose, items of a well-known and established measurement instrument for connection to nature, the CNS by Mayer and Frantz (2004), were used.

STUDY 1

In study 1, we tested the measurement tool used by Klain et al. (2017) for its convergent and discriminant validity. For this purpose, we compared the RV measurement with the well-known 2-MEV model using a sample of 350 university students. In a second step, we examined the reliability of the RV measurement scale using test–retest reliability on three different samples: a group of university students and two groups of high school students.

Methods

Measurement of Relational Values and the Two Factor Model of Environmental Values Scale

Since RVs have only recently received more attention in empirical research, there are no established and repeatedly used measurement instruments available. Nevertheless, there have been several attempts to measure RVs. Chapman (2017) conducted interviews with 22 farmers and land managers, wherein they identified different values, including RVs. This approach is probably effective, although it requires a lot of time and considerable effort. Arias-Arévalo et al. (2017) chose an open-ended questionnaire to measure instrumental, intrinsic, and relational values. Using the same approach as Chapman (2017), they assigned values to the statements, and data analysis revealed that intrinsic and relational values outweighed instrumental values. Furthermore, Uehara et al. (2018) developed seven relational statements based on the seven definitions for RVs by Chan et al. (2016). Participants had to rate the statements on a five-point Likert scale from strongly disagree (1) to strongly agree (5).

Our study is based on a questionnaire developed by Klain et al. (2017) who modified seven value statements derived from studies about cultural ecosystem services (**Appendix 1**). Each of the items used emphasizes a different focus: community, health, identity, kinship, responsibility, wild places, and environmental impacts.

In terms of content, the seven statements fit well with the definition of RVs. The community item covers the aspect of RVs that sees place and nature as a tool to connect people to a community. The health item describes nature as an aid to increase health and well-being of a person and other people. This aspect is an important part of RVs. The items identity and kinship reflect the personal connection to plants, animals, and land as a part of the personal identity. The remaining three items (responsibility, wild places, and environmental impacts) include the stewardship and care for nature, special places, and other people. This relationship shows that the seven items applied well represent the construct of RVs.

The item responsibility had to be slightly revised because the questions were originally used to consult farmers and tourists. Instead of "How I manage the land [. . .]," we asked, "How we manage the land [. . .]." We translated the items to German and, similar to the original study, our participants had to rate the statements on a five-point Likert scale.

Two factor model of environmental values scale

The 2-MEV Scale is a well-known measurement tool for ecological values developed by Bogner and Wisemann (2006). The model consists of two higher factors: preservation and utilization. Preservation represents the preference to conserve and protect nature, and utilization represents the use or exploitation of nature for benefits. The scale is used regularly, and its validity and structure are proven many times (e.g. Milfont and Duckitt, 2004; Johnson and Manoli, 2010; Boeve-de Pauw and Van Petegem, 2011). In recent research, Bogner (2018) extended the scale with a third factor: appreciation of nature.

For our study, we selected the five highest loading items on preservation as well as on utilization from Bogner and Wisemann (2006). Furthermore, we added the five highest loading appreciation items from Bogner (2018).

Procedure and Participants

Convergent and discriminant validity

To test for convergent and discriminant validity, 350 biology students (69.4% female, 27.7% male, 2.9% no answer) were surveyed. More than 90% of the study participants were aged between 18 and 26 years. The participation in our survey was voluntary, and all respondents were of full age. A majority of the students (n = 271) were enrolled in the course "Diversität der Organismen & Lebensräume" (Diversity of Organisms & Habitats) at Goethe-University Frankfurt. This basic course is usually taken in the second semester of the Bachelor of Science (Biology) and Teacher Training in Biology programs. The questionnaires were handed out at the beginning of the courses, and the students decided for themselves if or when they wanted to fill in the survey. To prevent coercion, the students were asked to leave the questionnaire on their table after the course, so it was possible to give back empty questionnaires anonymously. The other 79 participants answered the questionnaire during Bioscience Education seminars in the same month (July 2018). We received 350 out of 450 questionnaires, which corresponds to a response rate of 77.78%.

Test–retest reliability

For verifying test–retest reliability, we selected new groups that have not previously participated in the validity test. The reason for this is a possible influencing of the results if the participants had seen and completed the questionnaire before. The recommended sample size for testing test–retest reliability is at least 100 (Kline, 1999). To prove test–retest reliability, the measurement tool was tested over three different time intervals. We asked university students who participated in the course Human Biology (M_{age} = 24.15 $\pm$2.44) to complete the questionnaire at the beginning and at the end of the winter semester 2018/2019 3 months later (mid November 2018 and mid January 2019). From the initial 73 students, 53 completed both questionnaires. The second group consists of 45 pupils from a local school who participated in a program called Goethe Biolab week (M_{age} = 16.17 $\pm$0.877). The second questionnaire was conducted 5 days after the first one by 37 pupils. This part of the survey took place in April 2019. Forty-eight pupils participated in the last group (M_{age} = 16.80 $\pm$0.707), visiting the Opel Zoo in Kronberg (Germany) in March 2019. All students of this group attended to both questionnaires before and after the zoo visit, 2 h later. For their participation, the students got free entrance to the zoo and a guided tour. If students did not complete the questionnaire, they did not suffer any disadvantages. The survey participation was voluntary, and participants under the legal age had to bring a signed letter of agreement by their parents. Privacy policy has been respected.

Analysis

All statistical analyses were executed using IBM SPSS 24. To assess the discriminant and convergent validity of the RV scale and the Pearson correlation between RVs and the appreciation, the preservation as well as the utilization items were calculated.

To determine the test–retest reliability, the Pearson correlation coefficient between the two measurement points of the three groups was calculated.

Results

The Pearson correlation between the seven RV items and the five appreciation items was medium (r = 0.469; p < 0.001), between RV and the preservation items high (r = 0.553; p < 0.001), and between RV and the utilization items negative (r = −0.284; p < 0.001).

For the 3-month test group, the value of the correlation coefficient was r = 0.837 (p < 0.001; M_1 = 3.64 $\pm$0.790; M_2 = 3.61 $\pm$0.696), r = 0.720 (p < 0.001, M_1 = 3.75 $\pm$0.664; M_2 = 3.79 $\pm$0.648) for the 5-day group and r = 0.756 (p < 0.001; M_1 = 3.61 $\pm$0.680; M_2 = 3.73 $\pm$0.750) for the 2-h group.

Discussion

Convergent and Discriminant Validity

Convergent and discriminant validities are important parts of construct validity. A measurement tool is considered as convergent if it is related to other measurement tools that measure the same or a similar construct. In contrast, a measurement tool is classified as discriminant when it is unrelated to measurement tools measuring distinct constructs (Campbell and Fiske, 1959). A common approach to evaluate both kinds of validity is to use Pearson correlation (Lehmann, 1988). For convergent validity, a correlation under r = 0.5 should be avoided (Carlson and Herdman, 2012).

In our study, we expected a positive correlation between RV and the appreciation items and between RV and the preservation items because all three are potential motivators for people to conserve nature (Wiseman and Bogner, 2003; Van den Born et al., 2017; Bogner, 2018). The calculated Pearson correlation coefficient between RVs and appreciation for nature almost showed a high effect (r = 0.469). For RVs and preservation, the correlation was high (r = 0.553). These results add evidence for convergent validity of the RV construct because preservation, appreciation, and RVs reflect a positive attitude toward nature. Comparable studies for other measurement tools reported similar correlations to verify convergent validity (Mayer and Frantz, 2004; Perkins, 2010; Olivos et al., 2011; Pasca et al., 2017).

In comparison, for discriminant validity, the correlation with divergent measuring instruments should be noticeably lower than the correlation with convergent measuring instruments (Hubley, 2014). We expected a divergence between RVs and utilization as the utilization items describe nature as an object that can be used by humans. This assumption was underlined with the obtained correlation (r = −0.284), adding evidence for discriminant and therefore for construct validity.

Test–Retest Reliability

To test the consistency of a measurement, reliability should be determined. In addition to the α-coefficient, the test–retest method is a common approach to verify reliability. For the test–retest, the same questionnaire is applied to the same test group on different occasions, and results are compared by correlation (McIntire and Miller, 2007). A correlation of $r \geq 0.7$ represents an acceptable reliability (Domino and Domino, 2006).

There are several factors influencing the result of the test–retest reliability. For example, the time gap between the testing and the sample size. Test–retest reliability is unsuitable for testing knowledge or skills because the first test is a practice for the second one, and participants could remember the answers (Domino and Domino, 2006). RVs are a part of human attitudes toward nature, and as part of the habitus (Ishihara, 2018), they should not change over a short period of time. The results revealed a sufficient correlation for all tested groups adding further evidence for reliability of the measurement tool. The 3-month group reached the highest value, while the 5-day and the 2-h groups scored slightly lower but still over the cutoff value of $r \geq 0.7$.

STUDY 2

In study 2, we executed a series of PCAs on the same sample of 350 university students used in study 1 (Section "Convergent and Discriminant Validity") to explore the fundamental structure of the concept of RVs. In this context, we compared an established CNS with the measurement of RVs to explore the overlap of these constructs. To this end, we used a shortened version of CNS.

Methods

In a first step, a PCA with the seven CNS items was conducted to confirm the single-factor structure of the shortened CNS version for our test group. In a second step, a PCA was used to explore the structure of the seven RV items. Finally, a third PCA was applied to examine the connection between CNS and RVs.

Measurement

Connectedness to nature scale

Connectedness to nature scale was developed by Mayer and Frantz (2004) to measure the connectedness to nature. In contrast to other measuring instruments, such as the New Ecological Paradigm (NEP) (Dunlap et al., 2000), CNS measures the affective experience rather than the cognitive beliefs. Since CNS is a 14-item scale, it is possible to assess it for reliability [in contrast to INS Scale by Schultz (2002)]. Perrin and Benassi (2009) criticize the CNS construct because their study shows that CNS does not measure emotional connection to nature. They argue that Mayer and Frantz used words that do not imply emotional connectedness (e.g. I fell [.]). Nevertheless, Perrin and Benassi (2009) agree that CNS is a suitable tool to measure beliefs regarding connection to nature. The scale has often been used in recent studies, and its reliability has been repeatedly confirmed (e.g. Mayer et al., 2009; Gosling and Williams, 2010; Cervinka et al., 2011; Olivos et al., 2011; Zhang et al., 2014; Navarro et al., 2017).

For our study, we selected seven of the 14 items with the highest factor loading, provided by Mayer and Frantz (2004), to keep the questionnaire compact. Since Mayer and Frantz (2004) carried out five surveys in their study, the factor loadings were averaged based on the number of participants. Validity, reliability, and correct measurement of connectedness to nature were proven for a reduced CNS (Pasca et al., 2017).

Participants

For study 2, the data set of the 350 university students from study 1 was reused. The sample size was adequate according to Comrey and Lee (1992), who suggest at least $n = 300$ for factor analysis.

Analysis

All statistical analyses were executed using IBM SPSS 24. To investigate the relationship between CNS and RVs, a series of PCAs were performed. The Bartlett test and the Kaiser–Meyer–Olkin (KMO) test were applied.

Results

A PCA with oblique rotation was conducted to confirm the single-factor structure of the reduced CNS. The number of factors was set at one, as proposed by the developers of the scale (Mayer and Frantz, 2004) and other authors (e.g. Olivos et al., 2011). The first factor accounted for 57.7% of the variance after the lowest loading item (>0.3) was removed (**Table 1**).

The six remaining items had factor loadings between 0.666 and 0.827. The KMO test approved the sampling adequacy (KMO = 0.869). Furthermore, the Bartlett test was highly significant; therefore, the conditions for factor analysis were fulfilled. To verify the reliability, Cronbach's alpha was determined ($\alpha = 0.849$).

The second PCA was used to examine the internal coherence of the seven RV items as a single dimension. To reappraise the single-factor solution by Klain et al. (2017), the number of factors was fixed to one. The result showed acceptable factor loadings (>0.50) for all seven items (**Table 2**). The factor showed an eigenvalue of 3.022, and the next eigenvalue was 1.011 (**Figure 1**).

To answer whether RVs and CNS are different or overlapping constructs, a third and final PCA with the seven RV and the six CNS items was performed. A two-factor solution was obtained, revealing a partial separation of CNS and RVs. Two CNS items loaded for both factors (**Table 3** and **Figure 1**).

TABLE 1 | Result of the principal component analysis with oblique rotation for shortened Connectedness to Nature Scale (CNS).

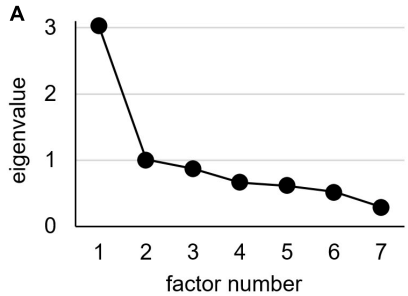
		Factor loading
CNS_6	I often feel part of the web of life.	0.827
CNS_5	Like a tree can be part of a forest, I feel embedded within the broader natural world.	0.805
CNS_2	I often feel a sense of oneness with the natural world around me.	0.794
CNS_4	I think of the natural world as a community to which I belong.	0.768
CNS_1	When I think of my life, I imagine myself to be part of a larger cyclical process of living.	0.680
CNS_7	I feel as though I belong to the Earth as equally as it belongs to me.	0.666

$\alpha = 0.849$

TABLE 2 | Result of the principal component analysis with oblique rotation for the seven relational value (RV) items.

		Factor loading
RV_IDEN	I have strong feelings about nature (including all plants, animals, the land, etc.); these views are part of who I am and how I live my life.	0.804
RV_HEALTH	My health or the health of my family is related one way or another to the natural environment.	0.698
RV_KIN	Plants and animals, as part of the interdependent web of life, are like "kin" or family to me, so how we treat them matters.	0.682
RV_WILD	I often think of some wild places whose fate I care about and strive to protect, even though I may never see them myself.	0.670
RV_ RESP	How we manage the land, both for plants and animals and for future people, reflects my sense of responsibility to, and so stewardship of the land.	0.644
RV_COMM	There are landscapes that say something about who we are as a community, a people.	0.549
RV_OTHER	Humans have a responsibility to account for our own impacts to the environment because they can harm other people.	0.508

$\alpha = 0.775$



B

component	eigenvalue
1	3.022
2	1.011
3	0.872
4	0.662
5	0.615
6	0.519
7	0.298

FIGURE 1 | (A) Scree plot and **(B)** eigenvalues of the seven factors of the principal component analysis (PCA) with the seven relational value (RV) items.

Discussion

General Considerations

The result of the first factor analysis proves the single-factor solution for our shortened and translated version of CNS. After the lowest loading item ($p < 0.25$) was removed, the loadings of the remaining items increased. Similar results were obtained by Pasca et al. (2017) with a seven-item CNS translated in Spanish. In comparison to this study, we reached a similar Cronbach's alpha (α = 0.866) and even higher factor loadings than Mayer and Frantz (2004) in the original study (α = 0.84). Therefore, in the case of α, sufficient reliability is proven (Tavakol and Dennick, 2011) that confirms scale usability for our further analysis. In the next step, we examined the coherence of the seven RV items as a single construct for our test group. Klain et al. (2017) previously showed for their test group that six of the seven items cluster together as a single-factor construct. For the test group, the forced single-factor solution has acceptable factor loadings (>0.5) and reliability (α = 0.775).

There are different criteria for determining how many factors need to be maintained in a PCA. One of the most common ones is the Kaiser criterion, which recommends that all factors with an eigenvalue > 1 be preserved (Fabrigar et al., 1999). For the analyzed data set, two factors show an eigenvalue > 1, bringing the number of factors to two. Jolliffe (1972) lowers the cutoff value and suggests extracting factors with an eigenvalue > 0.7, which in our case would mean obtaining three factors. A third commonly used option to determine the number of factors is to consider the point of inflection of the scree plot. The number of factors equals the number of factors on the left side of the inflection point excluding the inflection point itself (Field, 2009). For our data, the scree plot indicates a one-factor solution.

Depending on the criteria used, different numbers of factors are possible from the collected data. The tendency is toward a multi-factor solution. To clarify the RV structure, further analysis (study 3) is required.

TABLE 3 | Result of the principal component analysis with oblique rotation for the seven relational value (RV) items and the remaining six Connectedness to Nature Scale (CNS) items.

	Components	
	1	2
CNS_6	0.785	
CNS_5	0.779	
CNS_2	0.766	
CNS_4	0.742	
CNS_1	0.652	
CNS_7	0.628	
RV_KIN	0.568	0.377
RV_IDEN	0.556	0.543
RV_HEALTH		0.672
RV_RESP		0.672
RV_OTHER		0.661
RV_WILD		0.624
RV_COMM		0.540

Relational Value and Connection to Nature

Following these fundamental considerations, we discuss the two main questions of our study. Our results support the hypothesis that RVs and CNS have a certain overlap to some extent. The factor analysis of the CNS and RV items does not show a clear separation into two separate clusters, which would be expected for completely distinct constructs (**Figures 1**, **2**). Two RV items show positive loadings on both factors (>0.3). This outcome could be expected for the following reasons. The first overlapping item, "RV_iden," consists of a personal question to determine how much a person regards nature as being part of his/her life. The second overlapping item, "RV_kin," determines whether a person considers nature as some kind of family. Both items directly or indirectly measure some kind of connection to nature, which explains the loadings on both factors. If persons consider nature as being part of their lives or have a familiar solidarity with nature, the connection to nature will be higher. Consequently, CNS cannot be separated as clearly as the NEP from RVs, as revealed by Klain et al. (2017). Therefore, it is reasonable to assume that the concept of RVs includes, to a certain extent, a connection to nature.

STUDY 3

After study 2 could not provide sufficient evidence about the factor structure of RVs, we used CFAs on a different sample

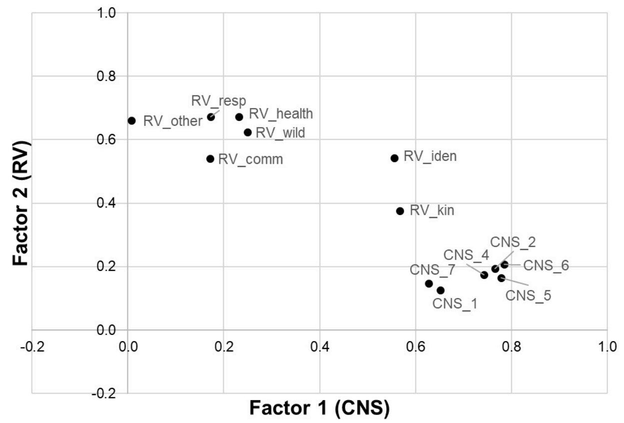


FIGURE 2 | Result of the principal component analysis with oblique rotation for the seven relational value (RV) items and the remaining six Connectedness to Nature Scale (CNS) items. Factor 1 represents CNS, and Factor 2 represents RVs. The results show an overlap between RVs and CNS.

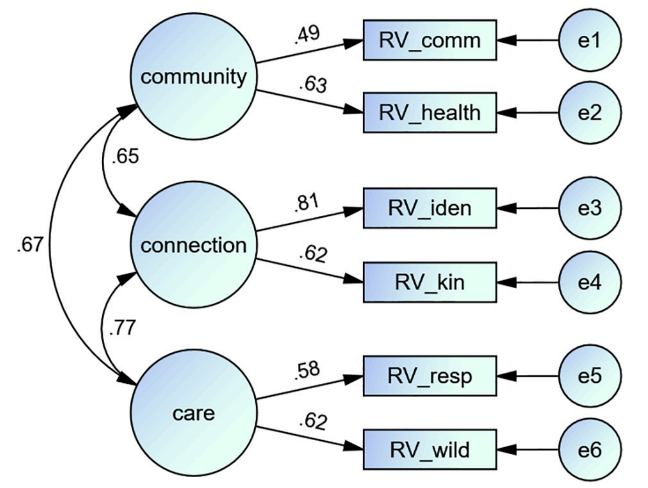


FIGURE 3 | Path diagram showing the result of the confirmatory factor analysis of model 3.

of students and pupils for further examination. Three models were developed and compared to evaluate the structure of RVs. Additionally, one model was tested to determine the result from study 2 that RVs and connection to nature are overlapping constructs.

Methods

Based on our findings from study 2, we tested the fit for four different models. Model 1 is a single-factor model with the seven RV items. This model matches with the assumption by Klain et al. (2017) and our forced factor analysis from study 2 (**Table 2**) that RVs are a single dimensional construct. The second model is a three-factor model based on theoretical assumptions about the concept of RVs and the results from study 2. The items RV_iden and RV_kin that showed affiliation to connection to nature in study 2 form one component (connection). The second component is formed by the items RV_health and RV_comm because both items represent the meaning of the land and environment for the community to some extent. The third component consists of the remaining three items, RV_wild, RV_resp, and RV_other. These items reflect the responsibility for the land.

Model 3 is an improved version of Model 2, based on the results of study 2. To enhance model fit, the lowest loading item (RV_other) was removed, bringing the number of RV items to six (**Figure 3**).

Model 4 was applied to verify the structure of RVs compared to the CNS. The six CNS items form one factor and the six RV items form three factors as in model 3 (**Figure 4**).

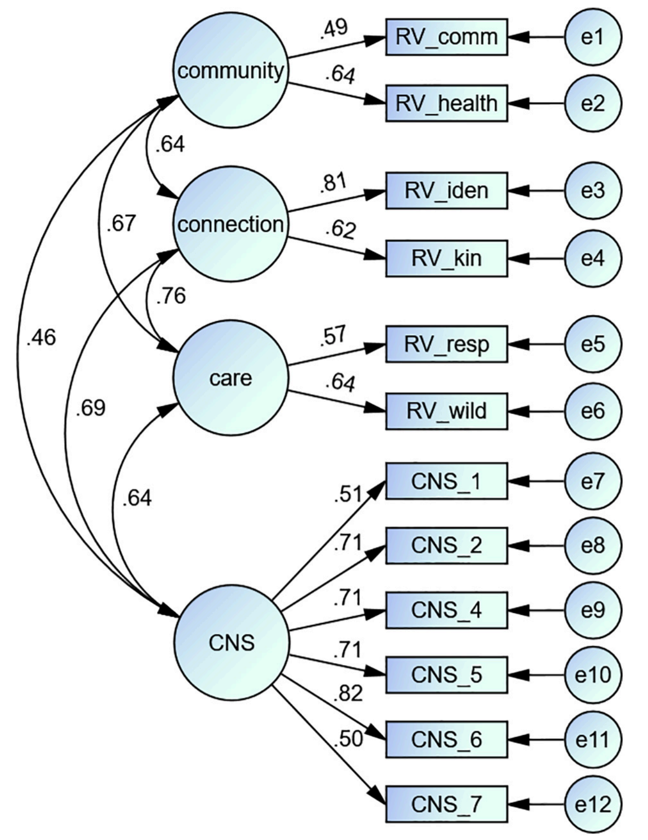


FIGURE 4 | Path diagram showing the result of the confirmatory factor analysis of model 4.

Participants

The sample consisted of 878 participants (62.9% female, 36.2% male, 0.3% no answer) and was determined by our goal to reach a meaningful sample size of more than twice the amount as in study 2. Slightly more than half of the participants ($n = 466$) were students from the Goethe-University in Frankfurt (Germany). The majority of university students (>77%) were between 18 and 23 years old. Most of the students were bachelor of science students in biology or other natural sciences ($n = 261$), while the remaining 192 participants were biology teacher trainees. Only 13 participants did not answer the question of which degree they would like to obtain. The survey method was the same as that used in study 1, but half a year later with different students. The remaining 417 participants were pupils (seniors) from local schools. Over 92% of the test persons were aged 15–18 years. In return for the participation in our study, the high school students received free entrance and a guided tour at the Opel Zoo in Kronberg (Germany). The study was advertised by e-mail to the local schools. If individual students did not take part in the survey, they still received free entrance and the guided tour. The survey participation was voluntary, and participants under the legal age were asked for a signed letter of agreement by their parents. Privacy policy has been respected. The data were obtained between October and February 2019 during the winter semester.

Analysis

The PCAs were performed using AMOS 26. Missing values in the data set were replaced with series means and as fitting function, maximum likelihood (ML) was used. Frequently used fitting variables to verify the suitability of the model were extracted [χ^2/df, root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), Comparative Fit Index (CFI), and Tucker–Lewis Index (TLI)]. For the CFI and TLI values, >0.95 are requested, for RMSEA values, <0.06, and for SRMR, <0.08 (Hu and Bentler, 1999). For a reasonable model fit, the ratio χ^2/df should be lower than 5 (Wheaton et al., 1977). Carmines and McIver (1981) even suggest three or less.

Results

Table 4 displays the model fix variables from the four tested models. **Figures 3**, **4** show the path diagram of the CFAs of models 3 and 4.

Discussion

Models 1, 2, and 3 were created to evaluate the structure of RVs, and our results provide evidence that RVs are not a single-factor construct as assumed by our first factor analysis. Model 1 (the single-factor solution) revealed insufficient model fitting with four from five tested fit indicators outside of the optimal range. On this basis, it can be assumed that RVs are a more complex construct, and a single dimension is not the optimal solution for RVs.

The second model includes the theoretical specifications of RVs that are described by Chan et al. (2016) and the results of our analysis in study 2 creating a three-factor model. RVs are not only the personal relation to nature (connectedness to nature) and relationships between people involving nature (community) but also the personal and societal values concerning nature (care). This result coincides with the view of Britto dos Santos and Gould (2018) who also see connectedness, community, and care as important parts of RVs. Model 2 showed a better model fit compared to model 1. Nevertheless, only two of the five fitting indicators were in the optimal range. In contrast to the two previous models, Model 3 has an optimal model fit with all tested fitting variables. Additionally, Model 3 is the only tested model that showed a p-value larger than 0.05 for the chi-square test, adding further evidence that our model fits the data (Schermelleh-Engel et al., 2003). The results provide evidence that RVs are not a single-factor construct as expected but have at least three dimensions.

To examine the relationship between the CNS and RVs, we analyzed a fourth model. Model 4 divided the RV items on the three factors (connectedness, community, and care) and the six CNS items on another one (**Figure 4**). The CNS showed a high correlation to the connection and care components of RVs ($r_{connection}$ = 0.69; r_{care} = 0.64). This result could be expected because these two components show similarities to the connectedness to nature concept by Schultz (2002). The connection component of RVs coincides with Schultz cognitive component, while the care component is similar to the affective component of nature connectedness. This result is not surprising. Various authors have shown that the concept of connection to nature can be interpreted more broadly and is closely related to concepts such as values or environmental identity. Tam (2013); Olivos and Aragonés (2011), and Brügger et al. (2011) found high correlations between the CNS and other established environmental scales such as the INS Scale and the EID Scale. The EID Scale attempts to capture the relationship between a person's identity and nature. This includes the connection to nature and natural objects as well as to geographical locations, which is called place identity (Clayton, 2003). This connection to places is also an essential part of the RVs. This example shows how closely related the various concepts of connectedness to nature are to RVs.

These findings show that RVs overlap with the concept of connection to nature. Both concepts contain the relatedness with nature and the environment and the care for natural things. Nevertheless, there are also some differences. RVs have a community component that tries to explain what the land, nature, or the environment means for a group of people. This component is not part of the nature connectedness concept.

The overall analysis provides evidence that RVs and connection to nature are not distinct constructs. RVs seem to contain a substantial part of the connectedness to nature concept but also add some additional content that is not part of connection to nature. For this reason, we assume that RVs are a useful concept to explain people decisions concerning nature and to explain proenvironmental behavior.

TABLE 4 | Results from confirmatory factor analysis for models 1–4 with a sample of 878 participants.

	χ^2	*p*	df	χ^2/df	RMSEA	(S)RMR	CFI	TLI
Model 1	156.14	<0.001	14	11.15	0.107	***0.063***	0.868	0.802
Model 2	60.10	<0.001	11	5.463	0.071	***0.044***	***0.954***	0.913
Model 3	12.43	0.053	6	***2.07***	***0.035***	***0.024***	***0.993***	***0.982***
Model 4	152.76	<0.001	48	***3.18***	***0.050***	***0.038***	***0.965***	***0.952***

Values in the optimal range are printed in italics and bold. χ^2, chi-square; df, degrees of freedom; RMSEA, root mean square error of approximation; (S)RMR, (standardized) root mean square residual; CFI, Comparative Fit Index; TLI, Tucker–Lewis Index.

GENERAL DISCUSSION

The concept of RVs that emerged in recent times tries to explain people's decisions concerning nature (Chan et al., 2016). Despite the large number of publications on the topic in the last few years, there is still a lack of empirical research. An important reason for this is probably the lack of an evaluated measurement tool. Therefore, we have examined an existing measurement tool. Using different samples, we provided evidence for convergent and discriminant validity of an RV measurement tool developed and used by Klain et al. (2017). Besides the different kinds of validity, we also prove reliability of the measurement tool by testing test–retest reliability and calculating Cronbach's alpha. For further analysis of the structure of RVs, we used a series of PCAs as well as CFAs. Since the PCA with the forced single-factor solution of the seven RV items did not show perfect results, the measurement tool was further analyzed using a larger sample size and a series of CFAs. Only the CFA with a three-factor solution for the RV items had sufficient model fit. Therefore, we conclude that RVs are a multidimensional rather than a one-dimensional construct. A comparison of RVs with the well-known concept of nature connectedness by using a shortened version of the CNS by Mayer and Frantz (2004) displayed a high accordance with two RV components. Despite the overlap of the two concepts, RVs are covering social aspects that are not part of nature connectedness. Our empirical study confirms the multidimensionality of the RV concept as assumed in theoretical research. Both Klain et al. (2017) and Britto dos Santos and Gould (2018) consider care and community to be part of the RVs. With the research conducted, this assumption can be empirically validated. In addition, Britto dos Santos and Gould (2018) consider connectedness to nature to be an elementary component of the RVs, which is confirmed by the overlap of RVs and CNS in a PCA in study 2 and CFAs in study 3. RVs are a possible influencing factor on the decisions of economic and political decision makers (Stenseke, 2018), but at the same time, there is a lack of empirical research (Schultz and Martin-Ortega, 2018). A concrete measurement tool for quantifying RVs was needed and is now available.

The multidimensional character of the concept, empirically proven in this study, can be used to justify decisions affecting nature and people, in addition to the intrinsic and instrumental values. If, for example, the care component is particularly developed in a community, it is necessary to pay special attention to it in economic and political decisions. As RVs play a more important role in local communities, decisions at this level should consider them.

The multidimensionality also makes it possible to place the RV construct in concrete relationship with already existing concepts of psychology and environmental psychology. The proof of the care component of RVs shows the concrete link with Stern and Dietz (1994) concept of biospheric values, which refer to the protection of the environment. The identified community component reflects the concept of benevolence by Schwartz (2012), and the connection component of the RV is clearly related to the cognitive component of Schultz (2002) concept of connection to nature. In future research, these aspects should be investigated and considered more closely.

Empirical research on RVs is particularly useful for environmental education. In environmental education research, factors such as environmental knowledge (e.g. Braun and Dierkes, 2017; Schmitz and Da Rocha, 2018), environmental attitudes (e.g. Pooley and O'Connor, 2000; Liefländer and Bogner, 2014), or connection to nature (e.g. Kossack and Bogner, 2012; Liefländer et al., 2013) are often reviewed and related to proenvironmental behavior. With the RVs, a new approach to explaining human behavior that affects nature has been added, which can now also be examined empirically. The three-dimensional instrument can be used to examine the success of environmental education programs and to determine whether the RVs are being promoted. The dimensions enable a differentiated approach in the evaluation of educational programs. It can be determined exactly in which context and extent a program contributes to the development of RVs. This allows environmental education programs to focus on a specific area of the RVs and track its success (or failure). Moreover, this seems particularly useful for regional and local environmental education programs. For example, promoting a concrete link to a place or the importance of that place to the regional community is an essential contribution that goes beyond connection to nature. Creating awareness of nature and place could therefore also be a starting point for future (especially regional) environmental education programs. The RVs have the potential to become a fundamental construct for evaluating the success of environmental education programs, alongside connection to nature, environmental attitudes, environmental values, and environmental knowledge. Especially regional environmental education programs could support local environmental protection by creating a connection between the community and the country or nature.

For this reason, we recommend further research on the topic of RVs especially to figure out the dependency of people's RVs and proenvironmental behavior. In this respect, the measurement scale of Klain et al. (2017) appears to be an adequate tool, and it can be assumed that there is a positive correlation between RVs and proenvironmental behavior. In this way, RVs could be a new approach to explain people's environmental behavior, as it is the case with the connection to nature (Kals et al., 1999; Frantz et al., 2005; Kaiser et al., 2008).

LIMITATIONS

Although the study was conducted with great care, some limitations need to be addressed. One methodological limitation is the survey group. University and high school students with a scientific focus were questioned. The respondents' views are therefore strongly influenced by natural sciences. It is conceivable and possible that students of the humanities, languages, economics, and social sciences would evaluate RVs differently. Furthermore, the selection of this sampling group tended to include people who are more in touch with education. In further research of RVs, it is essential to also include people who are less well educated. In addition, the majority of the respondents were young adults between the ages of 16 and 30. As a result, our study does not reflect the age structure in our western society. It can be assumed that there is a clear value difference between the generations (Inglehart, 1977), which should also be reflected in the RVs. In order to obtain a more precise picture of the construct of the RVs, it will be necessary to conduct further studies with a wider survey group. Moreover, it would be advantageous to cover different cultural areas (compare Schwartz, 1992; Inglehart, 1997).

Another methodological limitation is the use of a shortened Connectedness to Nature Scale. Since the questionnaire was answered during regular courses at the university, it was necessary to keep it as short as possible. Therefore, of the original 14 CNS items, only the six with the highest factor loadings were used. Although the reliability, validity, and correct measurement of reduced CNS were proven (Pasca et al., 2017), it is possible that information related to the RVs was lost due to the reduction. For example, it is conceivable that the overlap of the CNS with RVs would be greater or smaller on a full CNS than it was found in our study. For further research, it is necessary to also determine the relationship between RVs and CNS for the full CNS. In the same way, it would be useful to examine the relationship between RVs and NEP, as considered by Klain et al. (2017), for the complete NEP.

This investigation of the construct is only the beginning to the empirical investigation of the structure of RVs. Further empirical research is required, as well as more theoretical framework to add evidence on the three-factor solution of RVs. Despite our contribution, the demand of Schultz and Martin-Ortega (2018) for more quantitative research on RVs remains.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MK and PD conceived and designed the study and contributed to the final version of the manuscript. MK collected the data and performed the analysis and wrote the original draft.

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APPENDIX 1

RV_IDEN	I have strong feelings about nature (including all plants, animals, the land, etc.) these views are part of who I am and how I live my life.
RV_HEALTH	My health or the health of my family is related one way or another to the natural environment.
RV_KIN	Plants and animals, as part of the interdependent web of life, are like "kin" or family to me, so how we treat them matters.
RV_WILD	I often think of some wild places whose fate I care about and strive to protect, even though I may never see them myself.
RV_ RESP	How ***we*** manage the land, both for plants and animals and for future people, reflects my sense of responsibility to and so stewardship of the land.
RV_COMM	There are landscapes that say something about who we are as a community, a people.
RV_OTHER	Humans have a responsibility to account for our own impacts to the environment because they can harm other people.

RV_IDEN	Ich habe starke Gefühle für die Natur (einschließlich aller Pflanzen, Tieren, dem Land, usw.). Diese Ansichten sind Teil davon, wer ich bin und wie ich mein Leben lebe.
RV_HEALTH	Meine Gesundheit oder die Gesundheit meiner Familie ist auf dem einen oder anderen Weg mit der natürlichen Umgebung verbunden.
RV_KIN	Pflanzen und Tiere, als Teile des verflochtenen Netzwerks des Lebens, sind wie Verwandte oder eine Familie für mich, daher ist es wichtig, wie wir sie behandeln.
RV_WILD	Ich denke oft an unberührte Orte, deren Schicksal mir wichtig ist und die ich schützen möchte, auch wenn ich sie vielleicht nie selbst besuchen werde.
RV_ RESP	Wie wir das Land bewirtschaften, sowohl für Pflanzen als auch für Tiere und zukünftige Menschen, spiegelt unsere Pflicht und Verantwortung für das Land wider.
RV_COMM	Es gibt Landschaften, die etwas darüber aussagen, wer wir als Gemeinschaft, als ein Volk sind.
RV_OTHER	Die Menschen haben die Verantwortung für Auswirkungen auf die Umwelt zu tragen, weil sie anderen Menschen schaden können.

frontiers in Psychiatry

SYSTEMATIC REVIEW
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The Effects of Workplace Nature-Based Interventions on the Mental Health and Well-Being of Employees: A Systematic Review

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Mental health in the workplace is a societal challenge with serious economical and human costs. Most prevalent mental disorders in the workforce (e.g., depression), however, are preventable. There is widespread agreement about the favorable effects of nature exposure and consequently, nature-based interventions (NBI) in the workplace have been proposed as a cost-effective approach to promote good health among employees. The objective of the present study was to systematically review scientific evidence on the effectiveness of NBI to promote mental health and well-being among actual employees in actual workplace settings. The review was conducted and presented in accordance with the PRISMA guidelines. The literature search was performed on five databases (PubMed, Embase, CENTRAL, CINHAL, and PsycINFO), hand-searching of field-specific journals, and the reference lists of retrieved papers over the past 5 years up to November (13th, 2018). Studies were eligible for inclusion if they *(i)* were randomized or nonrandomized controlled trials; *(ii)* comprised samples of actual employees; *(iii)* implemented a workplace-based intervention with exposure to nature; *(iv)* included comparison conditions that displayed a clear contrast to NBIs; and *(v)* investigated the quantitative effects on mental health or well-being. No restrictions on type of employees or workplace, publication period, or language of the publication were set. Risk of bias was assessed using the Cochrane's RoB2 tool. Narrative synthesis was performed due to large heterogeneity in outcome variables. Of the 510 articles identified, 10 NBIs (nine papers) met the eligibility criteria. The outcomes were grouped in five categories: *(i)* mental health indices, *(ii)* cognitive ability, *(iii)* recovery and restoration, *(iv)* work and life satisfaction, and *(v)* psychophysiological indicators. Narrative synthesis indicates consistently positive effects on mental health indices and cognitive ability, while mixed results were found for the other outcome categories. Caution must be given when interpreting the current evidence in this emerging research field because of the diversity of NBIs and the overall high risk of bias in the individual studies. Although in this field often researchers have to balance scientific rigor and ecological validity, there is a need for large, well-designed and rigorously conducted trials grounded in contemporary theories.

Keywords: employees, environmental psychology, health promotion, green exercise, mental health, occupational health, occupational psychology

INTRODUCTION

It is time to expand the remit of occupational health psychology (1) due to the complexity (2), change (3), and globalization (4) of the labor market. A recent meta-analysis determined that workplace factors including imbalanced job design, occupational uncertainty, and lack of value and respect in the workplace, contribute to poor mental health (5). Emerging trends in occupational health psychology demonstrate a paradigm shift, an advocated turn toward positive psychology, which, instead of addressing mental illness and risk factors aims to focus on fostering employees' mental health, well-being, and cultivating a healthy workplace (6, 7). In spite of the evidence supporting the effectiveness of positive psychology interventions in the workplace (8), and although working life often involves the need to recover from stress, many workplaces are, in practice, often neglected as a setting for implementing positive preventive approaches. Yet, the working environment represents a vital and ideal context for the promotion of mental health (1, 9) which is an important complement to clinical mental health interventions (10).

Nature Exposure and Nature-Based Interventions

There is a general consensus about the favorable effects of nature exposure (e.g., viewing or spending time in green and blue space) within several systematic and narrative reviews [e.g., (11–18)]. A recent systematic review of 12 reviews underlined the benefits of exposure to nature in all-cause mortality, mortality by cardiovascular diseases, and mental health among adult populations (19). However, uncertainty about context-specific evidence (e.g., work setting) remains. Two main theories, attention restoration theory [ART; (20–22)], and stress reduction theory [SRT; (23–25)] outline a critical role for nature contact in terms of health. ART [e.g., (26)] holds a cognitive explanation as a prolonged focus on demanding (work) activity leads to mental fatigue and further to negative emotional states (e.g., lack of energy) as well as to impairments in cognitive and physical performance. Particularly, according with ART, natural stimuli attract spontaneous interest and enable restoration, i.e. renewal of depleted resources (e.g., capacity of directed attention) (27). Restoration refers to feeling refreshed, attentionally recovered coupled with positive emotions, and low levels of stress and arousal (28). SRT [e.g., (25)] elucidates the restorative impacts of nature on effective functioning (i.e. eudaimonic well-being) and emotional well-being (i.e. hedonic well-being). According to the theory, as a result of evolutionary development, individuals have an innate predisposition to automatically and immediately exhibit positive affect toward natural, vegetation-rich environments resulting in stress-reducing psychophysiological responses (29, 30).

Both, the evidence and the theoretical underpinning of the health benefits of nature exposure, lay the ground for so-called nature-based interventions (NBI). A generally accepted definition of NBI is lacking (31). Moreover, numerous terms are used such as nature-assisted interventions (32), nature-based therapeutic interventions (33), green care (34), and ecotherapy (35). In this review, based on revising previous operational definitions [e.g., (36)], we define NBIs as planned, intentional activities to promote individuals' optimal functioning, health and well-being or to enable restoration and recovery through exposure to or interaction with either authentic or technological nature. We augment other NBIs definition by including technological nature [e.g., through virtual computer-generated nature settings; (37, 38)] and by encompassing "recovery" in order to account for work and organizational psychology constructs, too.

Mechanisms Linking NBIs to Health and Well-Being

Both, ART (20) and SRT (25) discuss restoration as a core process, which is assumed to be triggered by spending time in nature. Restoration hereby is related to cognitive recovery, positive emotions and hedonic well-being, as well as low levels of stress and arousal (28). Focusing on the work context, the *Job Demands-Resources Model* [JD-R; (39)] predicts that personal resources can buffer the negative effects of (adverse) job demands on well-being (e.g., burnout). If those personal resources are depleted, they have to be restored, which can be achieved by certain activities (40, 41). Those activities are supposed to have certain characteristics, for instance psychological detachment and relaxation (41), which are very similar to the characteristic effects of nature exposure as proposed by ART and SRT. Nature based interventions trigger psychological detachment (mental disengagement from work, attentional recovery) because according to evolutionary perspectives humans are predisposed to pay attention to natural environments (see e.g., ART, as described in the previous paragraph). Work-related stress exposure is reduced, attention is directed away from job demands toward natural stimuli, which might allow the renewal of (work related) attentional capacity [see (27, 42)]. Additionally, SRT implies that nature contact elicits positive affect (because places rich in water and vegetation were favorable to survival or ongoing well-being). Positive affect in turn is influencing physiological stress responses (either acute or chronic), which in turn prepares the organism for appropriate adaptive behaviors (43). The specific environmental conditions provided by nature might offer an explanation for the favorable effects on physiological stress responses [see (44)], and therefore the support of relaxation. Plants, for instance, emit *phytoncides*, which have been shown to reduce blood pressure and alter autonomic activity. Other mechanisms that have been investigated are environmental biodiversity, negative air ions, microorganisms, less air pollution, cooler temperatures *via* their effects on cardiovascular, autonomic, gastro-intestinal and immune functioning, anti-obesity, and anti-diabetic processes (42, 44). A detailed presentation of the mechanisms, however, is beyond the scope of this review.

A Positive Occupational Health Psychology Perspective on NBIs

In this perspective, NBIs also stem from a salutogenic approach (33, 45) and can be classified as positive occupational health psychology interventions (POHP), which aim to support optimal functioning of people, groups, and organizations (46, 47). Workplace interventions can be categorized as primary, secondary, and tertiary. Primary workplace prevention interventions seek to counter the incidence of mental health issues by changing the work environment (48). From a primary prevention perspective, POHP emphasize the importance for an organizational approach centralizing the advancement of resources, development of strengths (49, 50), and the cultivation of subjective well-being and mental health (51). Workplace interventions at the secondary level are "ameliorative and worker-directed," aiming to modify employees reaction, coping and resilience toward stress, thereby preventing the progression of subclinical mental health symptoms to diagnosable conditions [(51), p. 3]. In terms of treating mental illnesses, tertiary prevention interventions aim to minimize its impairment on a person's functioning (52). NBIs can be allocated to either of those, depending on their application and implementation as NBIs comprise a high diversity in their design, settings, target populations (53, 54), and goals (55).

Particularly, the POHP view of mental health in the workplace as on a continuum, varying from flourishing to languishing (56, 57) is useful to the understanding of how NBIs can promote health and well-being to employees. Languishing individuals perceive their work and life as "hollow" or "empty" (58) and it can occur with or without the presence of a diagnosed mental illness. Yet, both states are dysfunctional and translate to reduced levels of well-being. Hence, the critical question is how to foster flourishing in the workplace. In organizational psychology the JD-R model (59, 60) describes workplaces as a function of job demands (e.g., work pressure), job resources (e.g., social support), and personal resources (e.g., self-efficacy). According to this model, strain arises when job demands exceed the employees' belief in their capability to cope with them. Further, the depletion or lack of personal resources increases the risk of poor mental health. Recovery enables employees to restore their resources in order to preserve full working capacities and physical and mental health (40). Exposure to nature can help employees to fulfill all four recovery experiences and thereby enable psychophysiological unwinding. According to Sonnentag and Fritz (41) an activity needs to be characterized by four specific recovery experiences to ensure recovery: *(i)* psychological detachment (i.e. disengaging mentally from work); *(ii)* relaxation (i.e. low sympathetic activation plus positive affect); *(iii)* mastery (i.e. experiencing competence and proficiency in nonwork related domains) and *(iv)* control (i.e. ability to choose and to decide which activity to pursue). NBI might provide all these experiences.

An Integrative Theoretical Framework for NBIs

It should be noted that a large variety of NBI types exists (32), e.g., horticultural therapy (61), care farming (62), green exercise (63), wilderness therapy (64), and green exercise, the latter defined as "adopting physical activities while at the same time being directly exposed to nature" [(65), p. 6]. This variety implies the need of a broad and flexible theoretical framework that can be adapted, depending on type of NBI, to specific contexts.

The synthesis of theoretical accounts from environmental psychology [*ART*, (20); *SRT*, (25)], work and organizational psychology [*JD-R model*, 39; *COR*, e.g., (66)] and positive psychology [*Broaden-and-Build Theory of Positive Emotions*, (67)] builds a strong foundation for considering NBIs as an affordable, upstream workplace intervention. In particular, NBIs as a POHP intervention have the ability to increase positive emotions at the workplace and thereby offer a pathway toward optimal functioning and well-being for employees in the long term. POHP bridges the gap of solely focusing on curing mental illness by including dedicated, proactive, good mental health strategies (68). Overall, the implementation of NBIs is desirable from the perspective of employees, employers and society as a whole [e.g., (69)].

State of the Art on NBIs and Purpose of the Present Study

In a systematic review, Annerstedt and Währborg (55) found consistent evidence for the effectiveness and appropriateness of NBIs as a novel approach in public health for varied states of ill health (e.g., mental and attentional fatigue, symptoms of depression, and mood disturbances). The systematic review revealed effects on psychological, social, and physical outcomes. A systematic review reported positive effects (i.e. greater feelings of revitalization, positive engagement, energy, reduced tension, confusion, anger, and depression) after only one single bout of green exercise as opposed to indoors (70). However, a subsequent systematic review highlighted that the evidence on the additional benefits of green exercise, as compared with indoor exercise, is still broadly mixed (71). Both reviews emphasize how methodological limitations of green exercise studies might explain such inconsistencies.

Experimental designs are rather scarce in both organizational contexts (72) and nature-related research (73) due to high realization costs, difficulties to implement and many confounding variables outside of the investigator's control (74).

As a result, a large number of experimental studies have been conducted among students' populations in simulated work settings [e.g., (75, 76)] instead of actual employees in real work settings. Thus, questions concerning the generalizability of the results (55), the dosage of nature (77) respectively the duration of contact with nature (78) causal pathways (44) and the cost-effectiveness as well as what features of nature might be more beneficial than others (54) still have to be clarified. On the other hand, studies on actual employees in real workplace settings do exist, although to the best of our knowledge, a review that synthesize such knowledge is still missing.

The objective of this review is to systematically synthesize and assess the existing empirical research on mental health and well-being outcomes on actual employees attending NBIs in their workplace. The focus of the review is on preventative approaches (primary intervention), while studies with employees suffering from diagnosed psychopathology (secondary and tertiary interventions) are omitted. In particular, the following research questions guided this systematic review:

1. What types of NBIs have been applied in real workplace setting?
2. What are the differential effects of different types of NBIs on employee mental health and well-being?

METHODS

Study Design

This systematic literature review employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (79, 80). Five databases (PubMed, Embase, CENTRAL, CINHAL, and PsycINFO) were searched systematically using keywords derived from the analysis of key studies (SG) (See **Table 1**).

TABLE 1 | Example search strategy for PubMed.

Search number	Search terms/Combination	Hits
#5	#4 AND ("adult"[MeSH Terms] OR "adolescent"[MeSH Terms])	80
#4	#1 AND #2 AND #3	211
#3	mental health OR well-being OR well being OR wellbeing OR restoration OR recovery OR psychological health OR psychological stress OR work stress OR job stress OR stress-related health OR Relaxation OR Ill health OR positive affect	793,866
#2	greenspace* OR green space* OR bluespace* OR blue space* OR greenery OR outdoor OR outdoors OR nature exposure OR nature contact OR nature sound OR natural environment* OR restorative environment* OR natural setting* OR park OR forest OR office landscaping OR nature-based OR garden	95,471
#1	workplace OR workplaces OR work place OR work places OR office OR offices OR occupation OR occupations OR employee OR employees OR worker OR workers OR staff OR personnel	483,400

The search was limited to title and abstract.

The search strategy was designed by SG and reviewed by TEM. The entire bibliographic search was conducted on the 8th–13th November 2018. Supplementary approaches of contacting key authors and hand searching for papers within the last five years (2013–2018) finalized the search process (SG, JBB). Hand-searching was conducted on the 14th–17th November 2018 in the following journals: BMC Public Health [Vol. 13–Vol. 18, keyword: "employee"], Journal of Environmental Psychology [Vol. 33–Vol. 59], Journal of Experimental Psychology: Applied [Vol. 19–Vol. 24 (3)], Journal of Occupational and Environmental Medicine [Vol. 55, issue 1–Vol. 60, issue 11], Journal of Occupational Health Psychology [Vol. 18–Vol. 23], Journal of Workplace Behavior Health" [Vol. 28–Vol. 33] and Scandinavian Journal of Work, Environment and Health [Vol. 39, issue 1–Vol. 5]. It was decided to search only for peer-published literature and to exclude grey literature (e.g., Open Grey Database) as it limits precise conclusion about quality (81).

Eligibility Criteria

Eligibility criteria were defined using the PICOS-Framework [e.g., (82)]:

- Population: employees;
- Intervention: any type of NBIs;
- Control: control group required;
- Outcome: any measurements of mental health and well-being assessed using questionnaire;
- Study Design: exclusion of observational studies.

Participants/Population

The intervention had to be a workplace-based intervention, targeting people who perform their job within the organization. NBI-related activities could occur elsewhere but had to be implemented in and/or by their workplace (i.e. location of employment) or offered by the employers. Studies introducing a nonworkplace intervention (e.g., community intervention) including persons in employment were not eligible. With regards to employee populations, a specific inclusion criteria was that only adults (≥ 18 years) were included in the samples. Experimental studies that aimed to create a realistic office setting but did not reflect a real workplace with employees (e.g., student populations) were excluded. Moreover, employees that suffered from a diagnosed mental illness were excluded as the focus of the study is more on prevention of poor mental health and fostering good mental health than it is on cure or condition management.

Intervention

Studies had to encompass at least one NBI integrating explicit and purposeful nature contact, either encompassing blue or green space. This could be accomplished through direct nature exposure to an authentic natural setting (e.g., being in a park, being surrounded by indoor plants, having natural window views) or through indirect nature contact such as technological nature (e.g., acoustical and visual features). Studies that solely investigated existing restorative design features and qualities (e.g., plant density) within the working environment without manipulating these features were excluded. Exercise- and physical activity–based interventions that took place outdoors only met the inclusion criteria when natural features (e.g., trees) were present and sufficiently described (i.e. met green exercise definition).

Within this systematic review, *nature* is generally defined as spaces including elements of living systems with flora and fauna across a range of scales and degrees of human management, from a minor urban park through to relatively untouched wilderness (83). The term *green space* describes vegetation (e.g., trees, parks, forests, grass, etc.), whereas *blue space* prominently features visible surfaces of water (e.g., lakes, rivers, coastal water) (13, 84). Nature contact includes various dimensions and differs in spatial scale, frequency, proximity, the sensory pathway (e.g., visual vs. auditory experience), the person's activities and awareness in a natural environment (73).

Comparison

Comparison conditions had to be no intervention-control conditions or to display a clear contrast to nature, encompassing equivalent interventions in a nonnatural environment (e.g., built or urban environment, indoors. with no visual access to nature elements such as a view on nature from a window).

Outcomes

To be eligible, studies were required to report quantitative data on mental health (e.g., optimal functioning) or well-being (e.g., experience of positive emotions) using questionnaires. Measuring psychophysiological indicators signaling stress responses (e.g., blood pressure) were desirable as secondary outcomes, but not mandatory as an inclusion criterion.

Study Design

Eligible study designs included: randomized controlled trials (RCTs), quasi-RCTs, controlled trials (CTs), randomized cross over trials (RXT), quasi-RXTs, and crossover trials (XTs). Observational studies and studies without a control or comparison group were not eligible. Only peer-reviewed fully published research was included. Papers that contained conference proceedings, dissertations or project description reports and book chapters were excluded. Additionally, secondary sources and study designs such as systematic reviews, meta-analyses and literature (narrative) reviews were also excluded. There were no imposed restrictions publication period or language of the publication.

Search Strategy

Files (.ris format) containing the exported search results were saved and imported into the Rayyan web tool (85) for removal of duplicates and title and abstract screening. After deduplicating, titles and abstracts were independently screened by two authors (SG, JBB). The percentage of abstracts for which the two reviewers decided to exclude differed (88% and 91.8%), resulting in 26 articles of conflict. These discrepancies were resolved through discussion with a third researcher (TEM), resulting in two additional excluded articles. Following this first screening phase, full-text copies from articles that appeared to fulfill the inclusion criteria or where uncertainty still existed were retrieved. Two authors (SG, TEM) individually determined the final eligibility based on the full-text.

Subsequently, differences in eligibility assessment of two papers were adjudicated through consensus procedure or when necessary with the involvement of a third researcher (GC). The reference lists of included articles were scrutinized to identify further relevant studies. Throughout the whole process, the prespecified inclusion and exclusion criteria were applied.

Assessment of Risk of Bias

The Revised Cochrane risk-of-bias tool for randomized trials (RoB 2) was employed to gauge the risk in the findings of included studies on the following clustered outcome categories: *(i)* mental health indices; *(ii)* cognitive ability; *(iii)* recovery and restoration; *(iv)* work and life satisfaction; and *(v)* psychophysiological indicator of health. It addresses five bias domains: randomization, deviations from intended interventions, missing outcome data, measurement, selection of reported results (86). Each domain was judged as *low*, *some concerns,* or *high risk* based on responses to signaling questions, resulting in an overall bias judgment for the specific study outcome being assessed. Two authors (DD, GC) independently determined the risk-of-bias, with any disagreements resolved by a third researcher (SG).

Data Extraction

A data extraction table was developed (SG). The extracted data included the lead author, year of publication, country, theoretical framework, study design, methodology, population characteristics, intervention type and description (i.e. setting, nature component, daytime), as well as reported outcomes. One reviewer (SG) abstracted the aforementioned information, which were double-checked by a second reviewer (JBB).

Due to the paucity of research addressing the question of interest, coupled with the heterogeneous nature of the clinical, methodological, and statistical approaches employed, it was not feasible to pool data across studies to calculate a single effect estimate as initially planned. Thus, a narrative synthesis was conducted with the aid of guidance documents (87). The incongruous nature of the data across the studies led the authors to conclude that a quantitative meta-analysis would potentially be misleading and inappropriate (88). After preliminary analysis of the design and participant characteristics across studies, the studies were organized according to intervention type and outcomes incorporating a risk-of-bias assessment.

RESULTS

A PRISMA flow diagram was developed to summarize the selection of the studies retrieved for the review process (see **Figure 1**). Briefly, of the 510 references obtained from the search, 24 articles remained after title and abstract screening. One article

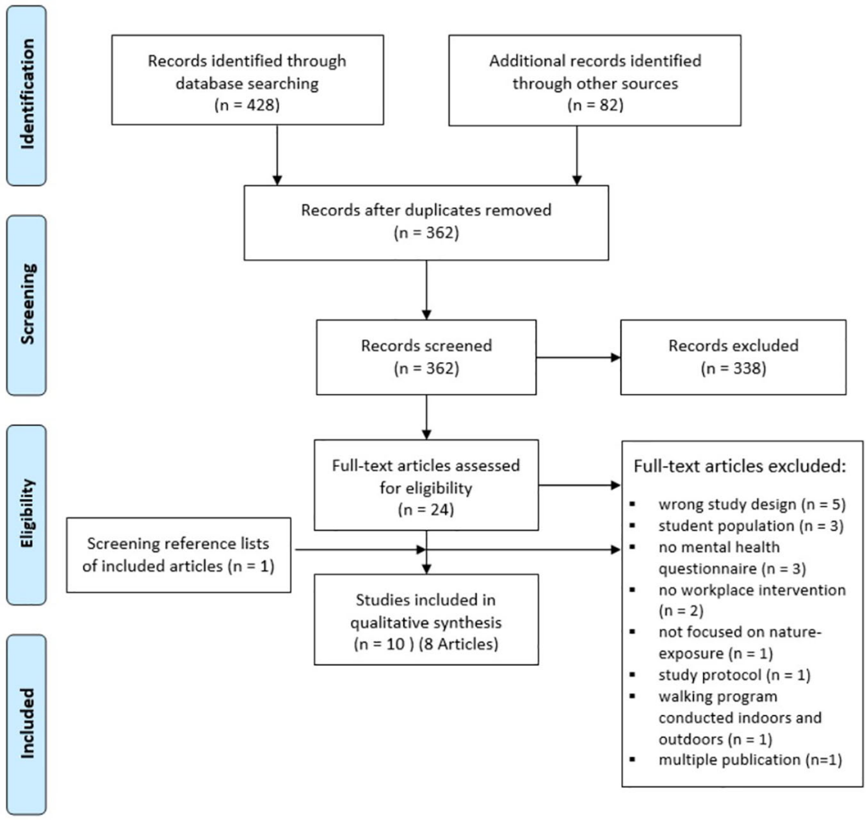

FIGURE 1 | Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of study selection and identification.

(89) was translated from Korean into English with the help of an international student with Korean as their first language, and one other article (90) was translated from Japanese with the help of a researcher with sufficient knowledge of the language. One abstract revealed to be solely published as a conference abstract; the authors were contacted in order to ask whether the data had been published or in press as a full publication, but a full-text copy could not be obtained. Five other articles did not contain sufficient information (e.g., characteristics of the environment with respect to the presence of natural elements), thus the authors were contacted for complementary information. Scrutiny of the reference lists of included publications resulted in one additional hit (91). Eventually, nine articles, containing 10 NBIs involving 611 employees overall, met the inclusion criteria. One article (92) comprised three independently conducted NBIs (further referred to 92). Two NBI trials had multiple publications (91, 93–96). For the first NBI trial with two publications, Calogiuri et al. (93) is the primary reference, as this article comprised quantitative analysis of well-being indicators (e.g., affect). However, additional outcomes regarding psychophysiological indicators in Calogiuri et al. (91) are reported. De Bloom et al. (94) and Sianoja et al. (95) refer to the same NBI, which was conducted as two independent RCTs phases with different participants (in spring and fall), but reported a different set of outcomes (94, 95). The third publication was excluded due to the absence of a questionnaire regarding mental health and well-being (96). The article by de Bloom et al. (94) analyzed and interpreted the results of both RCTs phases separately, while Sianoja et al. (95) pooled the RCTs together. Thus, due to an earlier publication date and the importance of weather and season variabilities in NBIs, it was decided to include the study by de Bloom et al. (94) as a primary reference and to report the RCT phases as two independent RCTs (further referred to as 94). However, two outcomes of the study by Sianoja et al. (95) are reported in this systematic review: the theoretical framework and the additional analyzed outcomes perceived stress and concentration. Here, it is necessary to bear in mind, that Sianoja et al. (95) included participants of both studies in de Bloom et al. (94). The remaining articles described one NBI each (89, 90, 93, 97, 98). For an overview of study and participant characteristics, see **Table 2**.

Study Characteristics

Eight NBIs had a longitudinal (i.e. comprising several weeks) RCT design, of which three also employed a *three-arm* parallel-group design (94, 97). Six NBIs used a RCT design with randomization at the individual level, while two randomized at the group level (green office space design studies) (92). The interventions' length ranged from 2 to 8 weeks. Although one pilot study implemented a brief intervention of merely two green

TABLE 2 | Study and participant characteristics.

Study (Author, year)	Country	Population	Overall N (% f)	Type of NBI	Dur. in (min)	Freq. per week	Length in weeks	Program	Type of nature	Control condition	Comparison/ experiment 2 condition
Bang et al. (89)	South Korea	office workers (faculty members + researchers in Seoul)	60 (92.6)	green exercise	40	2	5	urban forest-walking program	"palace area," park	no instruction	–
Brown et al. (97)	United Kingdom	office workers (desked based jobs in financial sector, one company at two sites)	94 (21.3)	green exercise	20	2	8	nature walking, circular walking route (approx. 2km), individually or with others	trees, spaces of maintained grass, public footpaths, country lanes	waiting control group	built walking group (BW): paved footpaths adjacent to roads, housing estates, industrial area
Calogiuri et al. (91, 93)	Norway	office workers (mainly office-based work, municipality employees, sedentary or moderately active)	14 (50.0)	green exercise	45	1	2	nature exercise program consisting of 2 parts: bicycling + strength session	forest area, grass-yard	–	bicycling + strength session in gym-hall, no visual nature contact, artificial lights, natural light filtered
de Bloom et al. (94)	Finland	diverse (knowledge-intensive + emotionally demanding jobs: public sector, administration, media, health care, finance, engineering)	83 (89.2)	green exercise coupled with nature savoring	15	5	2	park walk in nearest park, alone or in a group, instructed to pay attention to surroundings (savoring)	park	usual break activities	relaxation techniques: release-only version of progressive muscle relaxation, deep breathing + acceptance
de Bloom et al. (94)	Finland	diverse (knowledge-intensive + emotionally demanding jobs public sector, education, engineering)	70 (90.0)	green exercise coupled with nature savoring	15	5	2	park walk in nearest park, alone or in a group, instructed to pay attention to surroundings (savoring)	park	usual break activities	relaxation techniques: release-only version of progressive muscle relaxation, deep breathing + acceptance
Largo-Wight et al. (98)	USA (Florida)	office workers (university staff)	37 (91.8)	nature savoring	10-15	5	4	daily sitting outdoor work break while focusing on natural elements (e.g., clouds, sky, sounds, trees, grass, water)	any place outdoors	daily indoor standard self-selected work break, but not work-related	–
Matsunag et al. (90)	Japan	medical personnel (doctors, nurses, care workers of elderly health care facility)	72 (77.8)	nature savoring	5	1	–	enjoying view for 5 min, while "sitting still"	roof top forest (outskirts), bird sound, lawn, trees, plants, herbs, background: mountains	–	1st floor asphalted outdoor parking lot, during experiment cars were banned
Nieuwenhuis et al. (92)	United Kingdom	office workers (international consultants)	67 (41.8)	green office space	–	–	3	enrichment of office space by indoor green spaces in open plan spaces, at least 2 plants in direct view	large-leafed plants (90cm)	no changes: lean minimalist office space: no plants in direct sight, on the same floor	–
Nieuwenhuis et al. (92)	Nether-lands	office workers (call center agents of a	81 (81.5)	green office space	–	–	2	enrichment of office space by indoor green	large-leafed plants (90cm)	no changes: lean minimalist	–

(Continued)

TABLE 2 | Continued

Study (Author, year)	Country	Population	Overall N (% f)	Type of NBI	Dur. in (min)	Freq. per week	Length in weeks	Program	Type of nature	Control condition	Comparison/ experiment 2 condition
		health insurance company)						spaces in open plan spaces, at least 1 plant in direct view		office space: no plants in direct sight, on different floors	
Nieuwenhuis et al. (92)	United Kingdom	office workers (international consultants)	33 (51.5)	green office space	–	–	–	while working on cognitive tasks: office room containing eight large plants, at least 3 plants in direct view	large-leafed plants (90cm)	no further additions to office space, lean office space	–

f, females; Dur, duration; Freq, frequency.

exercise activities preceded by a exercise promotion workshop the previous week over a fortnight, it was classified as a longitudinal study due to the follow-up assessment of 2 and 10 weeks after the intervention (93). One other NBI applied a follow up measurement (after three and a half months) (92). Finally, one article included a preliminary cross-sectional survey on perceived feasibility of the NBI and a RXT investigating the effects of the actual NBI (90), and one employed an acute RCT design (92). The median sample size of studies was 70 participants and ranged from 14 (93) to 94 (97).

Theoretical Frameworks

Seven publications were based on an environmental psychology perspective (excluding 90) with five explicitly referring to ART (92–95, 98) of which one further employed the *SRT* (93). Additionally, four papers utilized biological and evolutionary explanations for the beneficial effects of nature (90, 92, 95, 98) with one mentioning the biophilia hypothesis (98). Five papers drew upon *green exercise* research (89, 93–95, 97) with Bang et al. (89) not incorporating the term *green exercise* in their study. Moreover, five papers integrated an occupational health psychology perspective by referring to worksite health promotion efforts (93, 98) and enrichment of office spaces (92). A stronger theory driven approach was taken by de Bloom et al. (94) and Sianoja et al. (95) by encompassing the *Effort-Recovery Model*, *Conservation of Resources Theory,* and *Recovery Experiences*. Only one paper referred to the *Broaden-and-Built Theory* (95). Therefore, this publication is the only one that undertook the synthesis of environmental, work and positive psychology. Finally, only one article used the *information-motivation-behavioral skills model* (90).

Country of Origin

The 10 NBIs took place in seven different countries. Three were conducted in the United Kingdom (92, 97) and two in Finland (94). The other NBIs were conducted in South Korea (89), Norway (93), United States (98), Japan (90) and the Netherlands (92). These countries differ largely on cultural dimensions like the value given to individualism, long-term orientation, masculinity and uncertainty avoidance (99–101). Due to this diversity, the countries cannot be considered as homogeneous in terms of society.

Participant Characteristics

Demographics

In total, 611 employees participated across the ten studies. The mean age of the participants ranged from 28 to 49 years with an overall mean age of 45.5 (SD = 4.95) years. Most participants were female (mean % female = 67%; median = 78%). One exception was the pilot study by Calogiuri et al. (93) with an exact gender split of 50%. However, the observed gender imbalance may be due to gender segregation in the labor markets, for example, financial sector (97), and education (89). Studies lacked an explicit reporting of ethnicity, with only two studies (97, 98) providing ethnicity data. In these two studies there was a predominance of Caucasians (mean = 82%). Only one publication including two experiments (94) reported additional sociodemographic factors such as educational level and household, revealing an overrepresentation of participants cohabitating with children and possessing a master's degree or higher.

Occupations

Seven studies comprised office workers, specifically: university staff (89, 98), finance employees (97), municipality employees (93), call center agents (92), and consultants (92). The study by Matsunaga et al. (90) involved doctors, nurses and care workers at an elderly health care facility (90). The remaining two studies (94) encompassed diverse employees in knowledge-intensive and emotionally demanding jobs from different companies and work sectors (public sector, administration, media, health care, finance, and engineering). Again, these studies were the only studies that captured work-related factors (e.g., permanent work contract, supervisory position, weekly work hours, work type such as blue- or white-collar worker, and tenure). Only Nieuwenhuis et al. (92) collected the number of work years for the company in study (a) and (b), too (92).

Intervention Types

Among all studies, different NBIs were identified and grouped into three categories: (*i)* green exercise, (*ii)* nature savoring, and (*iii)* green office space. Green exercise defines the synergy of physical activity and natural environment (65), whereas nature savoring is defined as mindfully noticing and attending nature while regulating the emotional impact of positive events by one's cognitive or behavioral response (102, 103). The third category, green office space, comprises interior landscaping interventions that aim to transform the design of workplaces by enriching plants and other natural features.

Green Exercise Program and Type of Nature

Five green exercise interventions were conducted and varied considerably in their implementation (89, 93, 94, 97). One common attribute across four studies was the time of intervention—employees' lunch break. Only the participants in the study by Calogiuri et al. (93) completed their green exercise in the afternoon following a regular working day. Bang et al. (89) implemented an urban forest-walking program under the direction of the researcher, which took place in a "palace area" with park. Brown et al. (97) provided a more detailed vegetation description including trees, spaces of maintained grass, public footpaths and country lanes. The employees could choose whether to walk the circular route (approximately 2 km) alone or in a group. Similarly, in de Bloom et al. (94) and Sianoja et al. (95) participants could decide whether to walk independently or collectively. The researchers introduced a green exercise intervention slightly coupled with a nature savoring component; the park walk instructions prompted participants' to pay attention to their surroundings and to avoid talking. The studies lacked a sufficient description of the type of nature (i.e. "nearest park"). Calogiuri et al. (93) was the only trial that implemented a green exercise program consisting of bicycling and strength training with an experienced instructor as opposed to walking programs. The cycling part was performed in a forest area, whereas the subsequent strength session was held in a grass yard. This publication was the only one that provided photographs of the natural settings.

Exercise Intervention Characteristics—The intervention length, and session duration, frequency, and intensity varied widely. For example, the program of both de Bloom et al. (94) experiments consisted of a 15 min slow, low-intensity walk on every working day (i.e. 5 days a week) within a 2-week intervention period (i.e. 10 sessions overall). Other walking programs employed a 5-week intervention with a duration of 40 min biweekly (i.e. ten sessions overall) (89) and an 8-week intervention with a duration of 20 min biweekly (i.e. 16 sessions overall) (97). Neither study reported the physical activity intensity. The average duration of green exercises ranged from 15 to 45 min (mean = 27 min). Calogiuri et al. (93) had participants exercise for 45 min (i.e. cycling for 25 min followed by a 20-min strength session using elastic rubber bands with handles). This exercise was performed at a moderate-intensity on 2 days over 2 weeks. To assess the reporting quality of eligible exercise interventions we used the 16-item Consensus on Exercise Reporting Template [CERT; (104)]. All five exercise interventions lacked sufficient information, resulting in a total score of nine (max. score = 19), respectively ten (93), after applying the CERT (JBB). Domains that were not addressed included the detailed description of motivation strategies, adverse events, and the extent to which exercise was tailored.

Environmental Conditions—Overall, weather conditions were poorly assessed and described. All five studies reported the intervention months: October–November (89), May–July (97), September (93, 94), and May (94). Three trials documented additional environmental conditions: 8°C –10°C with sunny conditions on the first day, overcast on the second day of green exercise (93), an average temperature of 15°C in spring, no precipitation and mostly sunshine, with daily temperatures up to 28°C (94) and an average of 14°C in fall with again no precipitation and mostly sunshine (94).

Comparators—There were substantial divergences in comparison conditions. In one study, the control group was given no instructions and told to have a regular daily life (89). Calogiuri et al. (93) compared green exercise with exercising indoors (i.e. gym hall) under identical conditions regarding duration, frequency, and intensity. Visual contact with nature was avoided and natural light was filtered. In two RCTs the control group was instructed to maintain their usual break activities. The other comparison, a second experimental condition, consisted of relaxation techniques, namely a release-only version of progressive muscle relaxation, deep breathing, and acceptance of the here-and-now (94). The remaining trial also employed two comparison conditions: a waiting control group and a built walking group without access to nature, comprised paved footpaths adjacent to roads (97).

Feasibility and Adherence—The validity of RCTs evaluating exercise programs depends strongly on participants' adherence rates, which reflects the attendance and compliance to the prescribed sessions. This varied largely across NBIs. For instance, in Calogiuri et al. (93), which consisted in an exercise promotion workshop followed by two green exercise sessions over a fortnight, all participants completed the NBI. The adherence to the study protocol in the two NBIs described in de Bloom et al. (94) was still fairly high, with 76% engaging in the green exercise condition or relaxation technique (comparison group) at least eight out of ten times within a 2-week time frame, respectively 72%. On the other hand, the longer intervention described in Brown et al. (97) reported quite a lower adherence rate of merely 43% in the nature and 42% in the built walking condition over an 8-week intervention.

Nature Savoring

Two studies implemented a nature savoring intervention employing markedly different designs.

Savoring Intervention Characteristics—In a 4-week longitudinal trial, office workers took a self-selected daily outdoor break during the work day for 10–15 min (a total of 20 breaks) while aiming attention at natural elements such as clouds, sky, trees, bird sounds, grass, vegetation, water, or fountains (98). The environment was no further specified than "any place outdoors." In the within-subjects design study by

Matsunaga et al. (90), medical staffs were exposed to a fourth story rooftop forest view on a single occasion (five min) while "sitting still in a wheelchair." This rooftop was covered with lawn, trees, and plants with mountains in the background.

Environmental Conditions—In Matsunaga et al. (90), the environmental conditions were reported to be sunny with an average temperature of 22.8°C and an air humidity of 37.4%. Weather conditions were not reported in Largo-Wight et al. (98).

Comparators—In Largo-Wight et al. (98), the control group undertook a daily indoor standard work break, which was self-selected in terms of time and location, but should not be work-related. In Matsunaga et al. (90), the comparison environment consisted in observing a first-floor outdoor parking lot. Order effects were minimized by creating sex- and age-matched groups starting either with the nature or comparison condition. Pictures of both environments were provided in the publication.

Feasibility and Adherence—Matsunaga et al. (90) reported no dropouts, although it should be noted the NBI (and its comparison) took place during one single day. In Largo-Wight et al. (98), prior to conducting the actual NBI, an online survey investigating the perceived feasibility of the proposed intervention was distributed among office staff. Responses revealed that participants perceived the study protocol to be feasible (74%), practical (80%), and worthwhile (83%). This was later confirmed when, actual the actual NBI, all employees reported a high compliance (88% not missing any assigned work break).

Green Office Space

All three NBIs in Nieuwenhuis et al. (92) demonstrated the enrichment of open plan office spaces by incorporating indoor green spaces using large-leafed plants (90 cm tall). The plants were continuously present over either 3 weeks (92) or 2 weeks (92). However, data were collected at baseline and after 8 (92) and 5 weeks (92), and the plants were installed for each intervention length followed by subsequent postintervention assessment. Each employee had at least one (92) or two plants (92) in direct view. The control group worked either on the same floor (92) or on a different floor (92) and both experienced no working environment change and continued performing their job in a lean, minimalist office space. In the third study, consultants worked on cognitive tasks at the end of the working day in a randomly assigned experimental condition green (at least three plants in direct view) vs. lean office space (92).

Risk of Bias

Each study outcome was categorized into one of the five clustered outcome categories [(*i*) mental health indices; (*ii*) cognitive ability; (*iii*) recovery and restoration; (*iv*) work and life satisfaction; and (*v*) psychophysiological indicators of health], assigned a unique ID and assessed for risk-of-bias (e.g., Bang_1; see **Table 3**). Thus, multiple RoB 2 assessments were conducted for each publication, in line with such clustering. An overall overview of the outcomes of the RoB 2 assessment is presented in **Figure 2**, whereas, the outcomes of the RoB 2 for the different outcome categories can be found in **Figures 3–7**, with "+" indicating *low risk*, "?" or "!" *some concerns* and "-" *high risk*.

Overall, not one study outcome out of 26 outcome measurements assessed displayed a low overall risk-of-bias. *Some concerns* (32% of outcomes) and *high risk-of-bias* (68%) were present in all outcomes due mainly to high-risk assessments in selection of the reported result (16%), measurement of the outcome (40%) and deviations from intended interventions (40%). Just two bias domains displayed no *high risk-of-bias:* missing outcome data (*low*: 72%, *some concerns*: 28%) and randomization process (*low*: 44%, *some concerns*: 56%). A summary of the risk-of-bias assessments for each clustered outcome category is presented below, alongside the respective findings for the respective category.

Mental Health Indices

Risk of Bias

Three study outcomes displayed a high overall risk of bias, due to contamination between intervention and control, respectively comparison group (i.e. working in the same building and discussing interventions with each other) (*deviations from intended intervention*; Bang_2, Brown_2) and very poor adherence and the failure to implement the intervention as planned (i.e. less than 50% of participants fully complied with the intervention) (Brown_2). Other reasons were high knowledge of the assigned intervention and its likelihood to influence employee-reported outcomes (*measurement of the outcome*; Bang_2, Brown_2, Sianoja_3) and trial protocol submission after data collection was finished (*selection of the reported result*; Brown_2). According to a trial protocol multiple indices of mental health measurements (e.g., perceived stress scale) and time points should have been collected (105), but were not reported or analyzed, without justification. Moreover, the statistical significant effect found for this outcome, alongside with a pooled sample size of two RCTs, suggest high a risk of selective *reporting of the results* (Sianoja_3). The other three mental health indices outcomes were judged to raise *some concerns* in at least three (Calogiuri_2) or four RoB 2 domains (Largo-Wight_1, Matsunaga_1).

Study Outcomes

Bang et al. (89) found no statistically significant difference in depression between green exercise and control group (t =.93, p =.358). Whereas in the nature savoring condition in Matsunaga et al. (90) female participants displayed significant decreases on the subscales depression-dejection ($p < .01$) and tension-anxiety ($p < .01$). Moreover, the mean values of state anxiety showed a significant reduction ($p < .01$) to 34.6 ± 8.1 (43.4 ± 8.4 for control) for male employees and to 36.3 ± 10.2 (45.8 ± 8.8) for female employees. Particularly, in women with a low- to medium trait anxiety, the state anxiety significantly (p < .01) decreased to a "very low" anxiety state after nature savoring, and in high trait anxiety females to a "low" anxiety state (p < .01). Across both genders, the scores revealed a significant increase in vigor ($p < .01$) postintervention. The subscales anger-hostility and confusion demonstrated no significance. In the study by Brown

TABLE 3 | Measured outcomes for each study with unique ID categorized to clustered outcome categories.

Clustered outcome categories					
Study (Author, year), type of NBI	**Psychophysiological indicators of health**	**Mental health indices**	**Work and life satisfaction**	**Recovery and restoration**	**Cognitive ability**
Bang et al. (89), GE	**Bang_1** Subjective PA, BMI, BC, BP, BD	**Bang_2** Depression (BDI)	**Bang_3** Quality of life (GHQ/QL-12)		
Brown et al. (97), GE	**Brown_1** Objective PA, BMI, HR, HRV, BP, CVD risk, Aerobic fitness, PH (SF-8)	**Brown_2** General mental health state (SF-8)		**Brown_3** Stress response + recovery (HR, HRV)	
Calogiuri et al. (91, 93), GE	**Calogiuri_1** CAR, BP serum cortisol, PA	**Calogiuri_2** Mood/affect: positive + negative Affect + tranquility (PAAS)		**Calogiuri_3** Perceived restorative-ness: fascination + being away (PRS)	**Calogiuri_4** Fatigue (PAAS)
de Bloom et al. (94), GE			**DeBloom_a_3** Job satisfaction (1 item)	**DeBloom_a_1** Restoration (1item) and recovery: RX + PD + enjoyment (3 items in total, 2 from REQ)	**DeBloom_a_2** Fatigue (1 item)
de Bloom et al. (94), GE			**DeBloom_b_3** Job satisfaction (1 item)	**De Bloom_b_1** Restoration (1 item) and recovery: RX + PD + enjoyment (3 items in total, 2 from REQ)	**DeBloom_b_2** Fatigue (1 item)
Sianoja et al. (95), GE		**Sianoja_3** Perceived stress/strain (1 item)		**Sianoja_1** Recovery	**Sianoja_2** Fatigue + concentration (1 item)
				RoB not performed as these measurements are the same assessed for de Bloom 2017	
Largo-Wight et al. (98), NS		**Largo-Wight_1** Perceived stress (PSQ)			
Matsunaga *et al. (90), NS		**Matsunaga_1** State anxiety (STAI), mood + subconstructs: tension-anxiety, depression-dejection, anger-hostility, vigor, confusion (POMS)			**Matsunaga_2** Fatigue (POMS)
Nieuwenhuis et al. (92), GO			**Nieuwenhuis_a_1** Workplace satisfaction (4 items)		**Nieuwenhuis_a_2** Concentration (1 item), Subjective productivity (2 items)
Nieuwenhuis et al. (92), GO			**Nieuwenhuis_b_1** Workplace satisfaction (4 items)		**Nieuwenhuis_b_2** Concentration (1 item), disengagement (6 items), objective productivity
Nieuwenhuis et al. (92), GO					**Nieuwenhuis_c_1** Concentration, cognitive performance (processing + vigilance tasks)

**For this RXT trial additional required considerations for the RoB assessment were followed. GE, Green Exercise; NS, Nature Savoring; GO, Green Office; PA, Physical Activity; BMI, Body Mass Index; BC, Body Composition; BP, Blood Pressure; BD, Bone Density; BDI, Beck Depression Inventory; GHQ/QL, Quality of Life Scale of the General Health Questionnaire; HR, Heart Rate; HRV, Heart Rate Variability; CVD, Cardiovascular Disease; PH, Physical Health; SF-8, Short Form Health Survey; CAR, Cortisol Awakening Response; PAAS, Physical Activity Affective Scale; PRS, Perceived Restorativeness Scale; RX, Relaxation; PD, Psychological Detachment; REQ, Recovery Experience Questionnaire; PSQ, Perceived Stress Questionnaire; STAI, State and Trait Anxiety Inventory; POMS, Profile of Mood States.*

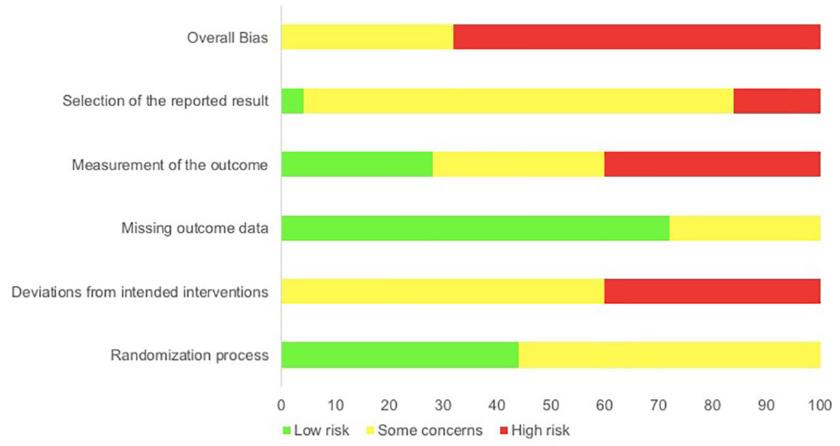

FIGURE 2 | Percentages summary of risk-of-bias assessment using the RoB 2 tool.

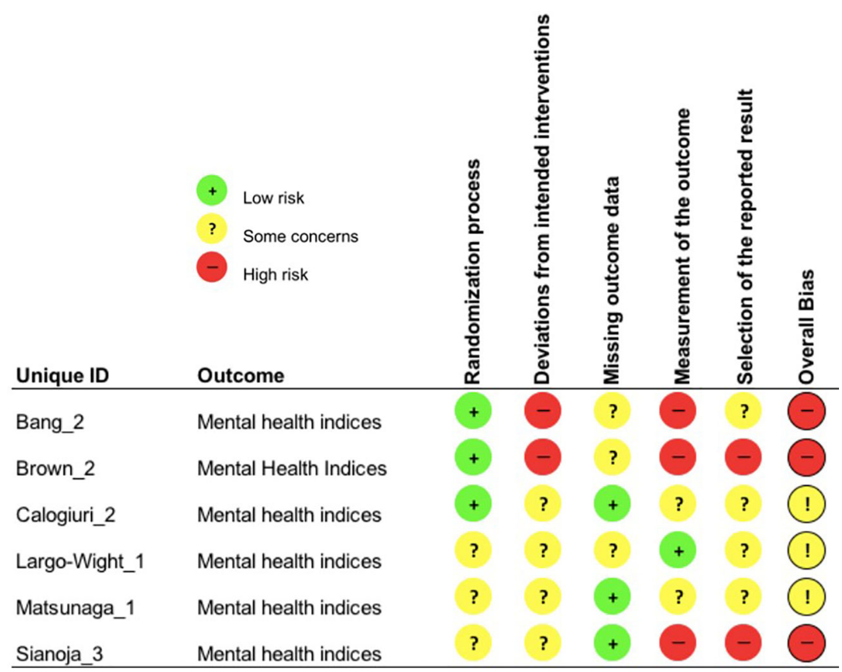

FIGURE 3 | Risk of bias assessment for the category mental health indices.

et al. (97), the green exercise participants displayed an increased self-reported mental health mean score by 2.7 above baseline score (95% *CI* 0.0–5.4) while the control group (−3.3; 95% *CI* −6.3–0.3) and built-walking group (−0.3; 95% *CI* −4.3–3.8) did not. Municipality workers in the green exercise condition from Calogiuri et al. (93) demonstrated only a marginally significant higher positive affect (p =.06) postexercise. Yet, these employees reported greater engagement with nature and scored higher on positive affect (p =.02) than the indoor group over a 10-week follow-up period. No significant difference was found for tranquility. Negative affect was excluded from the dependent variables due to poor normality. Office workers in the nature savoring condition displayed a significant lower posttest stress score (p =.041) compared to the control group, in a main effects ANCOVA model controlling for baseline stress (98). Interactions and additional covariates (e.g., sex) were not significant. Sianoja

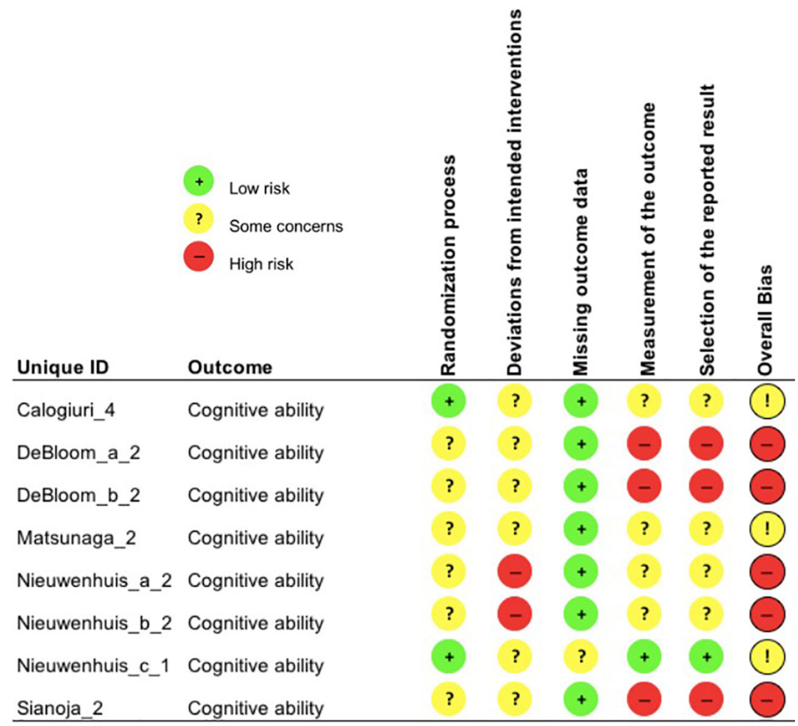

FIGURE 4 | Risk of bias assessment for the category cognitive ability.

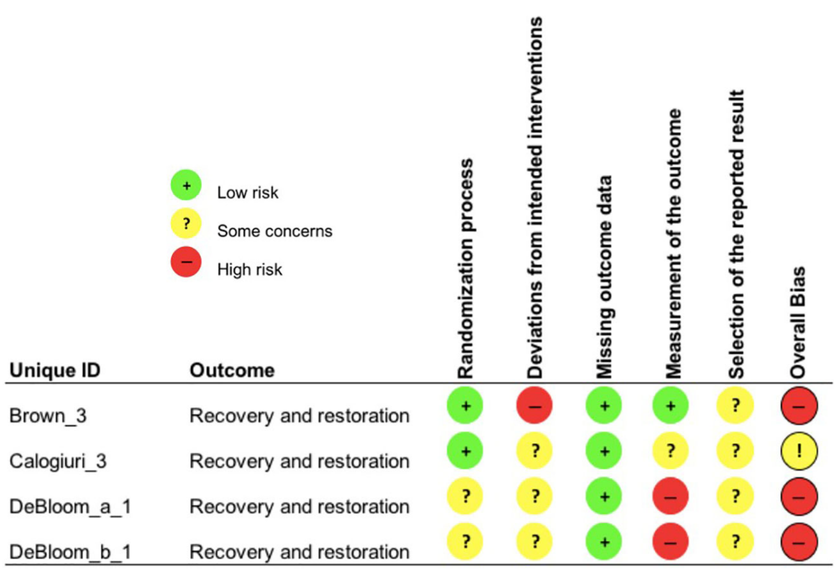

FIGURE 5 | Risk of bias assessment for the category recovery and restoration.

et al. (95) collected day-level data twice a week for 5 working weeks (NBIs in week 2 and 3). Green exercise predicted lower levels of afternoon strain on the within-person level ($\beta = -.34$, $SE = .17$, $p < .05$). However, the beta coefficient in the comparison group (relaxation exercises) revealed to be even greater ($\beta = -.60$, $SE = .18$, $p < .01$). Thus, employees reported lower levels of strain before leaving work, when they had engaged in green exercise or relaxation techniques during lunchtime. After the inclusion of

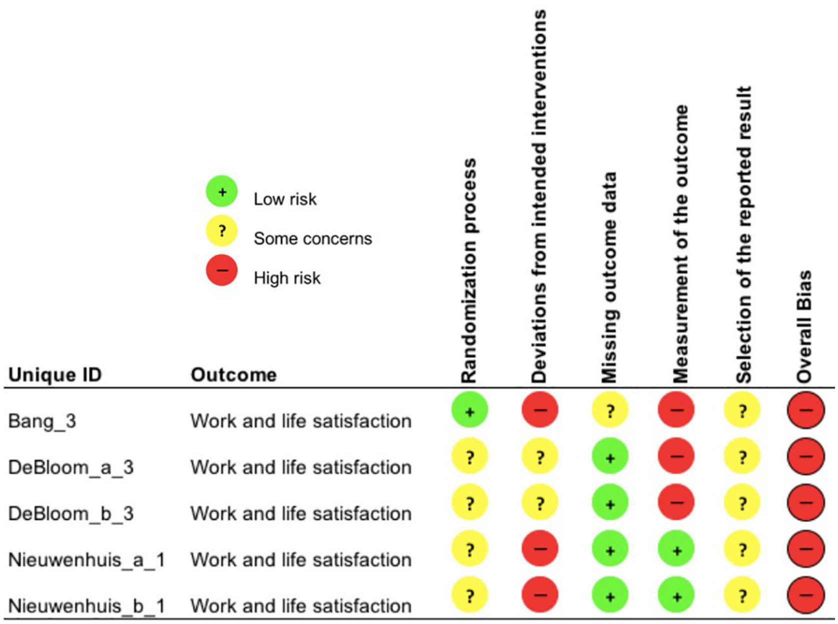

FIGURE 6 | Risk of bias assessment for the category work and life satisfaction.

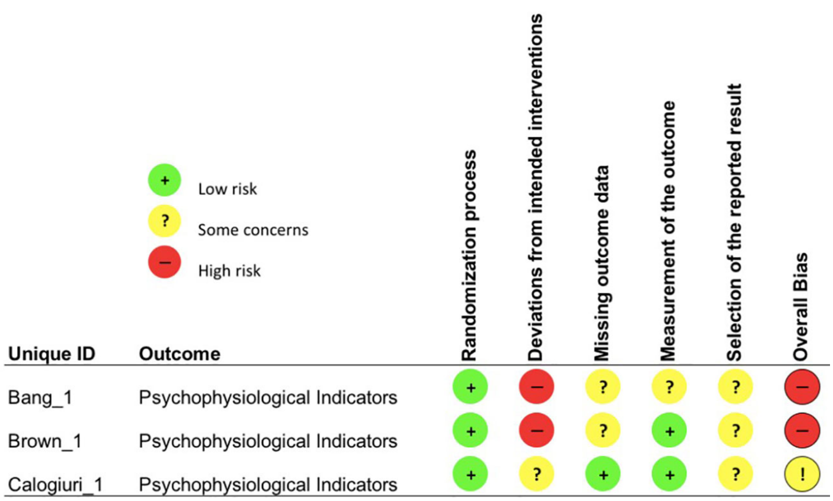

FIGURE 7 | Risk of bias assessment for the category psychophysiological indicators of health.

detachment (i.e. recovery experience) and enjoyment as mediator variables, the main effect for green exercise remained only marginally significant.

Cognitive Ability

Risk of Bias

The majority of cognitive ability outcomes (n = 5) showed a high overall risk of bias due to very large number of dropouts (Nieuwenhuis_a_2, Nieuwenhuis_b_2) and contamination between intervention and control group (*deviations from intended interventions*; Nieuwenhuis_a_2). Additionally, the rating of the domain *measurement of the outcome* resulted in a high overall risk of bias for three study outcomes: One-item measurements were used and elicit concern about reliability and validity, as well as the fact that employees had knowledge about assigned interventions, which was highly likely to influence their self-reported outcomes (DeBloom_a_2, DeBloom_b_2). The other three study outcomes on cognitive ability displayed *some concerns* overall (Calogiuri_4, Matsunaga_2, Nieuwenhuis_c_1).

Study Outcomes

Green exercise participants showed a trivial decrease in afternoon fatigue during the intervention period (d = −19, p < .05) and postintervention (d = −.22) compared to baseline (94). Whereas the control-group (i.e. no intervention) showed an increase in afternoon fatigue during the intervention period (d =.27). Surprisingly, green exercise participants reported an increase in fatigue in the evening (d = −.22). Repeated measures ANOVAs revealed no significant effects for group × time interaction on the between-subjects level. Participants in the second study (94) displayed lower fatigue directly after the lunch break (d =.52), in the afternoon during (d =.54, p < .05) and at the end of the intervention period (d =.29, p < .05). Afternoon fatigue in the control group increased after the intervention period (d = −.30). No effects were found for evening fatigue. Matsunaga et al. (90) reported that after viewing the rooftop forest (nature savoring), employees' fatigue significantly decreased (p < .01).

Employees in the green office condition in Nieuwenhuis et al. (92) self-rated their ability to concentrate higher after the introduction of plants ($F_{1,65}$ = 11.11, p =.001). In contrast, no significant difference over time was found in the lean condition ($F_{1,65}$ =.63, p =.431). Thus, there was a significant interaction for subjective concentration levels between office design and study phase ($F_{1,65}$ = 8.59, p =.005). This significant interaction could not be replicated ($F_{2,158}$ =.93, p =.40) (92). However, further model analyses revealed cross-lagged effects for disengagement on concentration between T2 and T3 (β = −.19, p =.030), i.e. between two weeks after the enrichment with plants and three and a half months later. Additionally, the cross-lagged effects for concentration on disengagement were significant between T2 and T3 (β = −.16, p =.040). While green vs. lean condition had no direct effect on concentration, it had an indirect effect on concentration at T3 mediated through disengagement at T2. Hence, the green office condition reduced call center agents' disengagement, which consequently had a positive effect on their concentration. The office design had no effect on objective productivity measures (i.e. total time in min call center agents spend on the phone) (92).

In Nieuwenhuis et al. (92), consultants in the green office space perceived their *subjective productivity* to be greater after the introduction of plants ($F_{1,57}$ = 3.81, p =.056, 95% CI [−.01,.16]) compared to consultants in the lean office space indicating a decrease in subjective productivity ($F_{1,57}$ = 3.04, p =.086, 95% CI [−.51,.03]). Yet, both simple effects failed to reach the critical significance level. In Nieuwenhuis et al. (92), cognitive performance tasks, representing office-based tasks (i.e. information management, processing, and vigilance) were used as opposed to subjective questionnaires. Consultants who completed the *vigilance* task in the green office condition, outperformed their counterparts in terms of time taken to complete it ($F_{1,30}$ = 7.91, p =.009). No significant effect of office design was found for the other tasks. In Sianoja et al. (95), a main effect on the within-person level for green exercise (β =.36, SE =.12, p < .01) on afternoon concentration was found. Hence, green exercise during lunchtime significantly predicted better afternoon concentration. Moreover, an indirect effect of green exercise *via* lunchtime enjoyment on afternoon concentration was identified (ab =.07, 95% CI [.02,.13], p < .05); with a proportion of the mediated effect of.16 (CI [.04,.42], p < .05). In Calogiuri et al. (93) fatigue was excluded from analyses because the normality assumption was not satisfied.

Recovery and Restoration

Risk of Bias

Three out of four study outcomes on recovery and restoration showed a high overall risk of bias as a result of contamination between groups and poor adherence (*deviations from intended intervention*; Brown_3). DeBloom_a_1 and _b_1 displayed a higher overall risk due to the same reasons as mentioned above (see cognitive ability). Only one study outcome was assessed as raising *some concerns* (Calogiuri_3).

Study Outcomes

No significant effects of green exercise were found on either HR or HRV in response to stress nor recovery from stress (97). In de Bloom et al. (94) the effect sizes for recovery experiences (i.e. relaxation, detachment) and enjoyment after lunchtime green exercise remained trivial (d < 0.15) during the intervention period. After the intervention period the green exercise group showed lower levels of enjoyment of their lunch breaks (d = 0.38). Contrarily, the within-group effects in de Bloom et al. (94) on relaxation (d =.66, p < .05), detachment (d =.61, p < .05) and enjoyment (d =.47, p < .05) were considerably higher and significant compared to baseline and control-group during the intervention period. Postintervention effects remained trivial again, ranging from d = −.12 to.09. A small (d =.23) but nonsignificant effect was reported for lunchtime restoration postintervention. Only trivial or no effects were found for lunchtime restoration during the intervention period (d =.17; control group: d =.47), evening restoration during the intervention period (d = −.03) and evening restoration postintervention (d =.12) (94). In the same study in fall (94) green exercise participants indicated higher levels of restoration after the lunch break (d =.33), and in the evening (d =. 26) during the intervention period. No effects were found postintervention. Statistically significant differences were reported between green exercise and indoor exercise groups on perceived restorativeness for both exercise sessions: Green exercise environment scored higher on fascination (p < .01) and being away (p < .01, respectively p =.01 for the first exercise session) (93).

Work and Life Satisfaction

Risk of Bias

All five study outcomes in the category work and life satisfaction displayed a high overall risk of bias. This was repeatedly due to *deviations from intended interventions* (Bang_3, Nieuwenhuis_a_1, Nieuwenhuis_b_1) and *poor measurement of the outcome* (Bang_3, DeBloom_a_3, DeBloom_b_3). Especially for study outcomes in Bang et al. (89) employees may have felt unlucky to have been assigned to the control group (i.e. no attempt of blinding) and therefore sought the experimental intervention (i.e. engagement in green exercise). Moreover, there were inconsistencies in the description and usage of the measurement tool, which favored the experimental group (Bang_3).

Study Outcomes

The green exercise group reported significantly higher quality of life than the control group postintervention (p =.020) (89). In de Bloom et al. (94), no effects of green exercise on job satisfaction were found. Whereas in de Bloom et al. (94), a small effect (d =.22) was reported for job satisfaction during the intervention period compared to baseline. The effect did not persist for postintervention (d =.08). Nieuwenhuis et al. (92) reported that the workplace satisfaction of consultants increased from baseline to postintervention ($F_{1,65}$ = 23.0, p < .001), but, importantly, the effect was not qualified by office design (p =.23). Thus, workplace satisfaction increased in both conditions. However, in Nieuwenhuis et al. (92) call center agents in the green office condition showed a significant increase in their workplace satisfaction ($F_{1,79}$ = 22.18, p < .001) two weeks after plants were introduced (T2). Moreover, the follow-up measure T3 (i.e. three and a half month after plants were introduced) showed that workplace satisfaction had only slightly changed in the long term ($F_{1,79}$ = 2.10, p =.151). The office design resulted in a significant direct effect on disengagement (β = −.15, p =.040) and workplace satisfaction (β =.37, p < .001) at T2. Thus, the call center agents in the green office space were less disengaged and more satisfied with their workspace. Further model analyses showed that disengagement predicted workplace satisfaction (baseline to T2, β =.19, p =.025; T2 to T3, β = −.24, p =.019). Hence, disengagement served as a moderator between office design and workplace satisfaction. Working in a green office reduced employees' disengagement and in turn fostered workplace satisfaction.

Psychophysiological Indicators of Health

Risk of Bias

Two out of three study outcomes displayed a high overall risk of bias judgment because of contamination between intervention and control, respectively comparison group (*deviations from intended intervention*; Bang_1, Brown_1) and very poor adherence (Brown_1). Furthermore, employees in the NBI condition were actively encouraged to be more active and to engage in additional green exercise within the experimental time frame, leading to a) additional health-related behaviors that differed between groups and b) to *some concerns* in the *measurement of the outcome* subjective physical activity (Bang_1).

Study Outcomes

No statistically significant effect of green exercise was found for anthropometric measurements (waist circumference, body weight, BMI) (89, 97), nor for body composition parameters (muscle mass, bone muscle mass, body fat), or bone density (89).

Concerning the cardiovascular parameters, no significant differences in CVD risk score, resting HR, or HRV were identified (97), while mixed findings were observed for *BP*: Bang et al. (89) reported no significant difference in either diastolic or systolic BP. Brown et al. (97) found a significant group*time effect in favor of green exercise for systolic BP (F = 5.53, p < 0.01), but not diastolic BP. Whereas Calogiuri et al. (93) found a marginally significant between-groups effect for diastolic BP (F = 4.91, p = 0.05), but not systolic BP. A significant between-groups effect was found for cortisol-awakening response with respect to increment (CAR_i) (F = 4.56, p = 0.04) but not for cortisol-awakening response with respect to ground (CAR_G), nor for cortisol morning serum concentration (93). Furthermore, a significant between-groups effect in favor of green exercise was found for self-reported weekly physical activity (89, 93), future exercise intention (B = 1.79, p < 0.01), and biking in nature (B = 0.84, p = 0.04) (93). No significant effects were reported for self-reported biking indoors [(93), see (91)]. Differently, no significant effect was found for objectively measured lunch-time physical activity or aerobic fitness (97).

DISCUSSION

The present study intended to *(i)* provide a synthesis of current quantitative research that applied NBIs within an occupational setting, and *(ii)* evaluate their effectiveness on employees' mental health and well-being outcomes. The 10 studies included displayed a large degree of heterogeneity in terms of design, nature exposure, assessed outcomes, and measurement tools, which precluded the possibility to conduct a meta-analysis. The wide range of applied outcomes was categorized into clustered dependent variables: *(i)* mental health indices, *(ii)* cognitive ability, *(iii)* recovery and restoration, *(iv)* work and life satisfaction, and *(v)* psychophysiological indicators of health. Furthermore, the different types of NBIs were grouped into three different types of NBIs: green exercise (five studies), nature savoring (two studies), and green office space (three studies).

Principal Findings

The findings of this review offer support for the positive impact of NBIs on employees, especially in relation to mental health indices. Five out of six studies found in fact statistically significant positive effects of the respective NBIs on self-rated mental health indices (90, 93, 95, 97, 98). The effects of NBIs in the workplaces the other clustered outcome variables (cognitive ability, recovery and restoration, work and life satisfaction, and psychophysiological indicators) were less consistent. Cognitive ability, which was investigated by the majority of studies [excluding (89, 97, 98)], showed only small to medium effects. The evidence on recovery and restoration, which was assessed in only four studies, was ambivalent, with two studies demonstrating positive effects (93, 94) and two studies stating no significant effects (94, 97). Of the five studies investigating the effects of NBI on work and life satisfaction, two were unable to demonstrate effects (92, 94), one found only a marginal effect (94), and two found statistically significant effects (89, 92). For what concerns the psychophysiological indicators of health, for which information was available only for three studies, it should be noted that each study included different anthropometric, hormonal, and/or cardiovascular measurements. Among these, only three measurements in two different studies showed statistically significant effects (93, 97).

With respect to the type of NBI, nature savoring was the only NBI that demonstrated exclusively significant findings (90, 98). Contrary to nature savoring, green exercise and green office space studies reported positive associations, but also nonsignificant and mixed findings. However, it cannot be deduced from these findings whether visual exposure to nature (i.e. green office space) combined with the mindful appreciation of natural elements (i.e. nature savoring) or physical activity in nature (i.e. green exercise) is more advantageous for the mental health and well-being of employees. On the other hand, outcome assessments of nature savoring studies displayed lower risk of bias (all scored “only” *some concerns* in the overall risk-of-bias judgment). All green exercise studies and green office space interventions, with one exception each (92, and 93, respectively), were on the other hand deemed to be of *high overall risk-of-bias*.

Weaknesses of Evidence

The included studies conducted NBIs in real-world environments, contributing to high ecological validity. However, weaknesses and shortcomings have been identified in terms of scope and description of natural environment, methodological quality, lack of study of confounding and mediating variables, impact the interpretability of results, and grade of evidence.

A challenge in this field is that the natural environment includes many diverse types, characteristics and amounts of green and blue spaces (e.g., wilderness areas vs. urban parks). All of the included studies were administered in green space. Based on the authors account, only Largo-Wight et al. (98) might have included presence of blue space. However, based on the available data, it is impossible to determine whether (or to what extent) the employees were actually exposed to environments including views of water, as the employees were merely instructed to take a work break outdoors in nature. Evidence suggests that the mental health benefits resulting from nature exposure varies not only by characteristics and quality of green space (106), but is also influenced by the proportion of blue space available (107). All green exercise and nature savoring studies lacked an adequate description of the natural environment, except for Matsunaga et al. (90) and Calogiuri et al. (93) that captured the greenery *via* photography. One reason for the lack of description can be attributed to the fact that the NBIs were carried out in multiple natural settings within one trial [e.g., (94, 98)]. However, measurement tools assessing and describing the quantity and quality of authentic natural spaces are well established [e.g., (13)].

The reviewed studies presents a number of methodical limitations, and are thus subjected to bias and confounding, displaying *some concerns* or an estimated *high* in the overall risk-of-bias assessment.

In some studies, the choice of the instruments used to assess mental health indices is, in our opinion, questionable. For instance, BDI is strictly speaking an instrument for evaluating the severity of depression symptoms [e.g., (108)]. In research and practice it is often used as a screening instrument, contrary to the field of application recommended by the authors (109). Furthermore, mental illness is no longer simply understood as the opposite end of the spectrum to mental health, but instead as part of a two continua model (56). Only two studies (93, 98) stated the reliability (Cronbach’s alpha) of the measurements used. Particularly for applied one item measurements (see **Table 3**), a minimum of test-retest reliability should have been reported. However, single-item measures may be adequate and suffice for some one-dimensional psychological constructs (e.g., job satisfaction) (110) to further reduce the response burden and length of questionnaires (111).

A main weakness concerns the lack of follow-up measurements and therefore, studies only describes short-term results, with the exception of Calogiuri et al. (93) and Nieuwenhuis et al. (92). Furthermore, the sample sizes and group sizes were generally small (mean of samples: n = 28) with absence of an adequate sample size calculation (excluding 89) to approve the number of included employees. Yet, this is pivotal in intervention studies (112). It is therefore ambiguous whether no significant effects or small effects were a consequence of insufficient power or a true indication on the outcomes measured. Particularly, de Bloom et al. (94) reported small effect sizes without reaching the statistical significance level. Other limitations concern the omission of sufficient description of baseline characteristics. Thus, sociodemographic group comparability was rarely explicitly described and analyzed.

Another major limitation is represented by insufficient treatment of confounding variables at an individual level as well as within the context. The concept of nature connectedness as individuals’ affective, cognitive, and experiential aspects of human-nature relationship has emerged as a correlate of psychological well-being (113, 114). Calogiuri et al. (93) was the only study that assessed nature connectedness at baseline—even though a meta-analysis suggests nature connectedness is rather a mediator of the benefits to good mental health (e.g., greater positive affect) (115). All green exercise and nature savoring studies stated the months in which the interventions took place. However, it is important to acknowledge the climatic differences both across and within countries, thus the information about months is not sufficient. Four out of six studies (90, 93, 94) provided additional information such as weather conditions and temperatures, which are a critical success factor in interventions taking place outdoors (17).

There are further numerous confounding or mediating variables that were not or could not be controlled within trials: environmental stressors (e.g., poor air quality), additional green exercise in leisure time (e.g., participants in 90 were encouraged to do so), work-related variables (e.g., exhaustion), physical spillover of green office design (e.g., 92), and social interaction. Particularly in green exercise studies in which employees could choose to walk individually or with co-workers (94, 97), a social component might have had an additional pleasant benefit. In

Largo-Wight et al. (98), the participants were instructed to sit outside and focus on natural elements. However, it is unclear, whether participants actually sat still or engaged in some sort of green exercise at the same time (e.g., walking to a bench). An issue that is prevalent in occupational research is the over-representation of female participants (116, 117) This was the case for six studies, whereas one showed an over-representation of males conducted in the financial sector (97) and three others were more or less balanced for gender (92, 93). Lack of blinding assessors, lack of blinding of participants to hypotheses, and lack of preregistrations was also an issue in many of the studies included.

Finally, another common limitation includes the absence of information about adverse events, side effects, unintended consequences, and safety issues. Poor reporting of adverse events was also acknowledged by the CERT (i.e. standardized method for reporting exercise programs), for which all green exercise studies scored rather low. There was a general absence of a preregistered protocol prior to study commencement (only 97, had preliminary registered the protocol). Hence, there might be potential risk of bias of due to inadequate analysis or selective reporting.

Strengths and Limitations of Review

To the best of the authors' knowledge, this is the first systematic review to address workplace NBIs both on actual employees and in real workplace settings. A main strength of this review is the identified transdisciplinary theoretical framework as a valuable foundation to guide the synthesis process and clarify the expected outcomes (118). Furthermore, multiple databases were used including Medline that independently provides a satisfying recall (approx. 90%) when searching for high quality studies within occupational health (119). The nonrestriction of publications in languages other than English resulted in two articles from the East Asian region. This was particularly important due to the practice of "Shinrin-yoku" (taking in the forest atmosphere or forest bathing), a traditional Japanese practice and growing parallel development within the East Asian region (120). To reduce the degree of subjectivity in this review, two independent reviewers with the help of a third researcher conducted the screening, the eligibility assessment, the data extraction and the risk-of-bias assessment. Moreover, a standardized tool to evaluate the risk of bias in the findings of included studies was used (86).

The main limitations and reasons for the weakness of evidence in this review were the paucity and heterogeneity of available studies. The outcome variables varied substantially among studies, e.g., for the outcome variable mental health indices seven different questionnaires were used: BDI, SF-8, PAAS, PSQ, STAI, POMS and one single-item instrument measuring perceived stress/strain. This made it impossible for us to conduct a quantitative synthesis of the findings (meta-analysis), which would have allowed to pool results together and estimate effect overall sizes.

While this study categorized each implemented NBI in one of three NBI types (green exercise, nature savoring, green office space), there were substantial divergences in delivery, activities, length and intensity. Moreover, it might be that additional NBIs studies may exist but escaped the search criteria, despite thorough exploration of appropriate keywords prior to final search. Due to the complex and broad vocabulary used for NBIs (55), there is the risk of having overlooked significant key words. Another limitation refers to the dispensation of database alerts after November 2018 – thought more hits do not necessarily mean more high quality studies. For an optimal trade-off between sensitivity and specificity of the search, information specialists and librarians could have been supportive as the recall of search is dependent on the skills of the end-user (119).

Within this systematic review, the new Cochrane RoB tool (RoB 2) was used and the assessment was conducted and implemented with the use of its manual and the recommend Excel tool. However, it was the first time that the authors used this particular tool. Disagreements between RoB judgments occurred, in particular because of terminology in studies being used inconsistently and because the interventions were complex [e.g., (121)]. Moreover, algorithm malfunctions within the Excel tool were identified (e.g., signaling questions indicated high risk of bias, algorithm resulted in low).

Implications for Practice

The knowledge base for formulating clear practical recommendations limits one to only tentative suggestions due to the scarcity of studies. The implementation of green exercise and nature savoring requires commitment and personal initiatives. Participation in the planning of the intervention design predicts higher commitment during the intervention period, and in turn positively influences intervention outcomes (122). This mechanism is particularly key for conducting NBIs, given that the experience of control is an important feature for a successful recovery process (123).

In general, the application of NBIs in terms of green exercise and nature savoring appears to be independent of the work sector, size of the company, and financial resources. This unique attribute differentiates NBIs from other work health promotion efforts. Moreover, to date no specific contraindications or negative side effects of NBIs have been determined (32). However, serious illness or allergies (e.g., hay fever) that prevent employees from going outside need to be determined prior to implementation.

Recommendations for Future Research

Research within occupational health psychology must constantly balance the tension between internal and external validity (124). Thus, interventions may have a lack of effect either as a result of weaknesses in their design or failures in implementation (125). Due to the abundant room for further progress in determining the effectiveness of NBIs within workplaces, only some will be highlighted. Firstly, there is a need for clearer definition and classifications of NBIs, and for an increased detail in reporting of them. Accurate descriptions, for example of the natural environment, might be beneficial to obtain more fine-grained analyses of different intervention modalities. With the high variability inherent in NBIs in work settings to date, it is crucial to clarify in future studies what natural environments with what natural stimuli and what activities are beneficial. A lack of transparency impedes reproducibility and generalizability of results, and consequently the accumulation of robust evidence.

When conducting workplace intervention research, blinding of employees from group allocation and conditions is often challenging or not feasible, leading to contamination of the control group. Cluster randomization may ameliorate this shortcoming (126). Furthermore, future studies require valid and reliable outcome measures combining physiological correlates of mental health and questionnaire-based outcome parameters. For the latter, research should consider measuring outcomes tailored to the work context and measuring constructs that derive from the theoretical framework applied, for example, workplace flourishing [Flourishing-at-Work Scale, FAWS; (57)], recovery experiences [Recovery Experiences Questionnaire; (41)], perceived restorativeness [Restorative Components Scale, RCS; (127)]. In particular, a consensus on what should be measured prior, during and following NBIs is reasonably needed in order to make research comparative. Thus, future studies should investigate not only short-term effects of NBIs, but also intermediate and long-term effects, especially regarding acquired resilience (128) and to establish how implementation holds up to a cost-benefit analysis over long term (124). Measurements of work productivity might also provide important information to evaluate the cost-effectiveness of NBI in the workplace.

Recent conclusions indicate a conceptual overlap and similarities between the environmental psychology concept of restoration and recovery in occupational health (129), calling for an amalgamation of both concepts from work, organizational, and environmental psychology (94). More research needs to be undertaken, to investigate this interesting prospect and consideration of contemporary conceptual frameworks (73, 130) would help generate additional testable hypotheses. It may also be possible in subsequent reviews, with the proliferation of theory-driven research, that theories could potentially be used to cluster the empirical articles, which would enable meaningful comparisons of the different explanations of diverse NBI's.

Future research needs to take various individual (e.g., age, nature connectedness) and workplace factors (e.g., organizational culture) into account to explore whether some employees or organizations might benefit more or less than others. This will give further insights into whether NBIs should be conducted on the organizational-level (i.e. targeting large groups of employees) as currently done or on the individual-level (e.g., only targeting employees that score high or low on nature connectedness or languishing). Another interesting field is to investigate effects of technological nature (131) for two reasons: firstly, to eliminate confounding variables that appear in authentic nature and, secondly, to include employees that might have reduced or no access to direct nature, for example, in industrial and manufacturing sites.

Despite suggested future research opportunities, NBIs in the workplace present complex interventions and therefore challenges denoting a high degree of connectivity between components and a large number and variability of outcomes (132). The Medical Research Council outlines best practice for design, implementation and evaluation of complex interventions. In particular, prior to developing an intervention, a thorough theoretical understanding is required to anticipate the changes and causal chain induced by the intervention. Similarly, Hartig et al. (42) emphasize a need for theory to advise research which nature types, and which features of those types, are relatively effective for particular outcomes. Process evaluation has a key role in any stage of the intervention, to assess the feasibility, optimize its design, evaluate effectiveness, transferability and generalizability (133). In particular, process evaluation is needed to reveal implementation failures as limited effects may be a result of implementation issues rather than genuine ineffectiveness.

CONCLUSIONS

This systematic review adds to our understanding of how NBIs can contribute to employees' mental health and well-being. The results showed predominantly positive effects on mental health indices and cognitive ability, but mixed findings for recovery and restoration as well as for psychophysiological indicators of health and life and work satisfaction. From the paucity and heterogeneity of studies, it is apparent that experimental research of NBIs in actual workplaces is in its infancy. This research area is challenging and complex, which resulted in high overall risk-of-bias of the individual studies. There is especially a need for theory-driven and well-designed trials.

AUTHOR CONTRIBUTIONS

SG designed and led the overall study, conducted the literature search, screened the potentially eligible papers, conducted and reviewed the data extraction, acted as a third part in resolving disagreements in the risk-of-bias assessment, and drafted the manuscript. TM contributed substantially in the ideation of the study and in determining the final eligibility of potentially eligible papers. JB-B provided substantial contribution in conducting the literature search, screening of eligible papers, and extracting the data from the selected papers. DD and GC conducted the risk-of-bias assessment. All authors substantially contributed to the writing up of various manuscript stages leading to the final version, which was approved by all authors.

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Natural Categorization: Electrophysiological Responses to Viewing Natural Versus Built Environments

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Environments are unique in terms of structural composition and evoked human experience. Previous studies suggest that natural compared to built environments may increase positive emotions. Humans in natural environments also demonstrate greater performance on attention-based tasks. Few studies have investigated cortical mechanisms underlying these phenomena or probed these differences from a neural perspective. Using a temporally sensitive electrophysiological approach, we employ an event-related, implicit passive viewing task to demonstrate that in humans, a greater late positive potential (LPP) occurs with exposure to built than natural environments, resulting in a faster return of activation to pre-stimulus baseline levels when viewing natural environments. Our research thus provides new evidence suggesting natural environments are perceived differently from built environments, converging with previous behavioral findings and theoretical assumptions from environmental psychology.

Keywords: environment, electrophysiology, LPP, ERP, natural, implicit categorization

INTRODUCTION

Natural environments can increase positive emotions (Roe et al., 2013) and creativity (Atchley et al., 2012), decrease stress (Ulrich, 1984; Mayer et al., 2009; MacKerron and Mourato, 2013; Hartig et al., 2014; Kuo, 2015; Von Lindern et al., 2017; Mennis et al., 2018), decrease impulsive decision-making (Berry et al., 2014; Berry et al., 2015), and are preferred over built images by adults (Kaplan et al., 1972; Meidenbauer et al., 2019). Natural environments can also improve working memory (Triguero-Mas et al., 2015) and attention (Hartig et al., 1991; Tennessen and Cimprich, 1995; Wells, 2000; Kuo and Faber Taylor, 2004; Berto, 2005; Berman et al., 2008; Mayer et al., 2009; Debener et al., 2012; Hartmann et al., 2013; Lee et al., 2015; Dadvand et al., 2017; Torquati et al., 2017; Ulset et al., 2017; Van Hedger et al., 2018; Stevenson et al., 2019).

Attention is often required when engaging in a behavior (i.e., maintaining attention to an ongoing task). If a person continues to engage in the behavior, their perceived cost in attentional resources is likely outweighed by the potential reward gained from continuing the behavior. However, with time on task, a person's likelihood of continuing the behavior decreases as attentional resources, which are finite, deplete. This depletion is experienced as mental fatigue (Kaplan, 1995). The fatigability of attention can thus be conceptualized as a cost-benefit analysis (Boksem and Tops, 2008), and mental fatigue can be understood as the point at which the perceived attentional costs of continuing a behavior are greater than the potential reward gained from continuing that behavior. Maintenance of attention to engage in a behavior can be guided by either top-down (endogenous and goal-driven) or bottom-up (exogenous and stimulus-driven) processes that support cognitive control (Posner and Petersen, 1990). Interacting with natural environments, such as taking a walk in the park, can improve performance on tasks designed to measure these systems of attention, especially endogenous attention (Ohly et al., 2016). Fewer cognitive resources may be needed to reach the same level of attentional performance when tested outdoors vs. indoors (Debener et al., 2012; Torquati et al., 2017). Such evidence suggests that interactions between attention and environment play a role in behavioral performance, specifically with respect to the onset of mental fatigue. Yet, there is little research to explain underlying mechanisms or physiological correlates of this relationship (Berman et al., 2019). It is important to understand biological underpinnings to this potentially transformative, yet low-cost and non-invasive, avenue for bolstering mental health and well being (Schertz and Berman, 2019).

Attention Restoration Theory (ART; Kaplan, 1989) largely drives this research. ART posits that certain environments better replenish attentional resources from a depleted state, based on five psycho-environmental characteristics: fascination, extent, coherence, being away, and compatibility. Fascination is an environment's ability to capture exogenous attention. Extent is the degree to which the environment is of large enough scope to keep exogenous attention engaged for more than a brief moment. Coherence, as defined within ART, is the degree to which the scene makes sense as a whole. Being away represents the conceptual removal of the potentially restorative environment from the fatiguing environment. Finally, compatibility represents characteristics of the potentially restorative environment that would facilitate a person's goals for restoration. Thus, the first three characteristics are responsible for an environment's ability to capture and hold exogenous attention, whereas the last two conceptually distinguish environments in which mental fatigue occurs (being away) and align with a person's restorative goals (compatibility; Kaplan, 1989, 1995; Kaplan and Berman, 2010). The theory posits that when finite resources for endogenous attention are depleted, the cognitive mechanisms for inhibiting distractions suffer. In this state of mental fatigue, environments that easily engage exogenous attention effectively allow these inhibitory mechanisms to rest and attentional resources to replenish; this is defined as attention restoration (Kaplan, 1989). Previous research has shown natural environments, when rated along these five characteristics, to be more restorative than built environments (Berto, 2005, 2007; Berman et al., 2008; Lee et al., 2015).

Studies driven by this theory concerning human responses to natural and built environments have primarily examined behavioral responses (e.g., Kaplan, 1989, 1995; Berto, 2005, 2007; Berman et al., 2008; Berto et al., 2008, 2010). Fewer studies examine how exposure to natural and built environments correlates with brain activity. Aspinall et al. (2013) conducted an EEG spectral analysis of how humans perceive walks through natural environments versus walks through built environments. Their data suggest general neural differences correlated with natural environments versus built environments, but do not pinpoint specific neural mechanisms. Another study reported cortisol differences correlated with exposure to natural versus built environments, postulating that these differences arise due to differences in stress (Roe et al., 2013). To our knowledge, though, no study has used the temporal sensitivity of EEG to investigate potential electrophysiological differences correlated with viewing images of natural versus built environments. It is possible that temporal differences measured by EEG, via event-related potentials (ERP's), can help elucidate physiological differences in humans while viewing natural versus built environments. Employing such methodology also enables the use of implicit measures.

In the present study, we specifically focus on the p3 and late positive potential (LPP) ERP components. The p3 correlates with detection of categorical differences: greater activation is found when a rare stimulus (the 'target,' i.e., not a member of a category commonly experienced within the experimental paradigm) is shown (Sutton et al., 1965; Rozenkrants and Polich, 2008). For example, p3 amplitude correlates with detection of changes in category of facial features (Azizian et al., 2006). Here, we use a set of diverse stimuli to represent distinct natural versus built environmental categories; stimuli within each category were determined prior to our electrophysiological experiment by a separate sample of adults who completed an explicit, binary environmental categorization task. Then, p3 activation to these two environmental categories was recorded while participants passively viewed a high frequency of multiple non-target stimuli representing one category (e.g., natural environments) and a low frequency of target stimuli representing the opposite category (e.g., built environments). Greater p3 amplitude for target stimuli, regardless of stimulus category (natural vs. built), is hypothesized. Such a finding from this passive viewing 'oddball' paradigm would provide electrophysiological support for implicit categorization of environmental scenes as natural versus built.

The LPP ERP component is examined most often with respect to stimulus valence (Bradley et al., 2007; MacNamara et al., 2009, 2011) or perceived pleasantness (Hajcak and Olvet, 2008). When a given stimulus (such as a building or landscape) is perceived as pleasant or unpleasant, rather than neutral, the LPP shows a slower recovery time to baseline levels of activation, which can be quantified by greater positive mean amplitude than is observed for neutral stimuli. Negative stimuli have greater positive amplitude than pleasant stimuli, while neutral stimuli show more baseline amplitude. Simultaneous recordings of EEG and fMRI taken while participants viewed affective pictures have shown LPP and blood oxygen level-dependent (BOLD) frontal activity to indicate contributions to perceptual categorization and emotional processing (Liu et al., 2012).

Previous behavioral research shows that natural environments correlate with a decrease in negative affect and are preferred over built environments (Kahn and Kellert, 2002; Berto, 2005, 2007; Berto et al., 2008, 2010; Falk and Balling, 2010; Aspinall et al., 2013). Previous data from EEG spectral analyses also suggest that natural environments hold greater positive valence than built environments (Aspinall et al., 2013; Roe et al., 2013), but LPP was not measured in these studies. We ask in the current study using the passive oddball viewing paradigm whether natural environments not only correlate with behavioral responses indicating preference, but also electrophysiological evidence in the form of LPP differences as well.

In sum, the current study employs a passive viewing oddball task in which stimuli from each of two environmental categories occur, with one category appearing at a high frequency and the other appearing at a low frequency. We examine the p3 and LPP ERP components correlated with viewing the stimuli. Hypotheses for this study are twofold: first, if natural versus built environments are implicitly perceived as being from distinct visual categories, a greater p3 should occur after viewing a target. Second, if natural environments are perceived as more pleasant than built environments, there may be a faster LPP recovery time after viewing non-target blocks of natural environments than after viewing non-target blocks of built environments. Either such result would identify electrophysiological markers signifying that humans implicitly categorize environments along dimensions of naturalness and/or pleasantness, and move closer to elucidating potential mechanisms and neural correlates underlying benefits of human exposure to natural environments.

MATERIALS AND METHODS

Participants

All participants signed IRB-approved consent forms. Students who participated received course credit toward their undergraduate psychology course work.

Categorization Sample

Fifty-one adults (21 Females; 18–38 years old; M = 23.58 years old) participated in a binary stimulus categorization task. Participants provided their gender, handedness, and age.

Rating Sample

Thirty-seven adults (21 Females, 1 unreported; 18–32 years old; M = 21.22 years old), different from those in the categorization sample, rated scenic images on an adapted version of the Perceived Restorative Scale (PRS) called the PRS short version (Berto, 2005; for original see Korpela and Hartig, 1996) and a preference item, which will be described below. Participants provided their gender, handedness, and age.

ERP Sample

Seventy-four right-handed adults (30 Females; 18–40 years old; M = 21.8 years old), different from those in each of the categorization and ratings samples, participated in a passive viewing task with stimuli assessed by the aforementioned categorization and rating tasks. Handedness was measured using the Edinburgh Handedness Inventory - Short Form (Veale, 2014). Data from 14 participants were rejected due to excessive noise in the signal (2), corrupted dataset (5), or EEG-to-computer interface issues (7). The remaining 60 participants were included in the ERP analyses.

Materials

Stimuli

Naturalness categorization

Four hundred and eighteen scenic images were crowd-sourced via lab Facebook page and lab contacts. Instructions for submission of photos were as follows:

> "The Multisensory Cognition Lab at USU is running a study on environmental perception, and is looking for participants to contribute stimuli to this study. If you would like to contribute some of your own photos, please send us your best photographs of different types of scenes – we are particularly looking for photos of a wide variety of natural settings and separate photos of manmade settings. Photos should be in color and should not contain people. They should not be easily recognizable landmarks that are commonly known to the general population. If we choose to use your photos in our experiment, they will first be rated by some of our participants and will then be viewed by other participants while they complete various cognitive tasks. They will not know you took the photos. You will not receive any compensation for or feedback about your photos. Please email childcognitioncenter@gmail.com with up to 10 photos if you would like to participate. Thanks!"

To determine categories of natural vs. built indicated by explicit behavioral choice, participants in the categorization sample were asked to categorize each of the 418 images as "natural" or "built" by placing their index fingers on the "q" and "p" keys on a standard keyboard and pressing "q" for "natural" and "p" for "built." The images were presented on a 19″ LCD monitor (aspect ratio 4:3) in randomized order across participants, in a self-paced task, via Eprime. Images rated as "natural" by 60% of these participants or more were considered "natural" stimuli, and those categorized as "natural" by 40% or less were considered "built" stimuli. This resulted in 227 natural and 162 built images submitted.

Perceived restorativeness ratings

The 418 images were randomly assigned to 8 subsets of images so that sets were a manageable size to be rated in one sitting by participants. Each subset was rated by 6–9 participants on the PRS-short items. This rating procedure and sample sizes of the rating groups were designed to be consistent with that of Berto (2005). Images within a subset were presented in randomized order across participants. Participants were instructed to view each image, read each statement carefully, and assess whether the statement applied to how they would experience the place depicted in the image. Images remained on the screen while the participants recorded their responses on a response sheet; this involved an 11-point (0–10) rating scale beside each statement, through which they would select from '0' indicating 'not at all' to 10 indicating 'very much.' After answering all items for one

SHORT VERSION OF PERCEIVED RESTORATIVENESS SCALE (PRS; Berto, 2005) and Preference Item (#6; Falk & Balling, 2010)

Please rate on the scale below the degree to which each statement describes the current picture

0	1	2	3	4	5	6	7	8	9	10
Not at all					**Rather much**					**Very Much**

1. That is a place which is away from everyday demands and where I would be able to relax and think about what interests me (being-away);
2. That place is fascinating; it is large enough for me to discover and be curious about things (fascination);
3. That is a place where the activities and the items are ordered and organized (coherence);
4. That is a place which is very large, with no restrictions to movements; it is a world of its own (scope);
5. In that place, it is easy to orient and move around so that I could do what I like (compatibility).
6. (The scene depicted is a place in which I would like to live.)

FIGURE 1 | Participants in the rating sample were instructed to rate each picture on the five PRS-short items (Berto, 2005) and the additional preference item (item 6 above; Roe et al., 2013).

image, the participant pressed the spacebar to proceed to the next. The average restorativeness score across participants for each image was calculated.

One further item of scene "preference" was included to be rated on the same 11-point (0–10) Likert scale as the PRS-short. The preference item, "The scene depicted is a place in which I would like to live," was adapted from Falk and Balling's (2010) investigation of landscape preference. See **Figure 1** for the PRS short version including the additional preference item by Falk and Balling (2010).

EEG Data Acquisition

The EEG data were acquired using the EEG Emotiv headset and TestBench software with 14 channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4) using Common Mode Sense active electrode and Driven Right leg passive electrode (CMS/DRL) references at P3/P4; left/right mastoid process alternative. Samples were collected at a rate of 128 per second (2,048 Hz internal) and scalp impedance were below 10 kΩ at recording onset. Data were preprocessed in EEGLab (Delorme and Makeig, 2004). Data were filtered (bandpass: 0.1–59 Hz), re-referenced to average scalp reference, and trials containing artifacts were removed algorithmically based on abnormal trend and improbable data (Delorme and Makeig, 2004). Independent component analysis was used to reject stereotypical eye blinking and jaw-related muscle clenching. Each trial length spanned 1,200 ms, where the first 200 ms served as baseline for the 1,000 ms post-event epoch.

Passive Oddball Viewing Task Procedure

Participants were seated in a chair 24 inches from the monitor. The experimenter placed the EEG cap on the participant's head and ensured that all electrode sites showed an impedance of less than 10 kΩ before starting data recording. Participants completed a passive oddball task with instructions as follows: "You will be seeing a series of pictures. View the images as they appear." After the instructions, the EEG headset was equipped for recording from participants. Participants were shown two blocks consisting of various images. Half of the participants first viewed the natural-non-target block, in which 80 natural and 20 built images were presented in random order. In the built-non-target block, image category frequencies were reversed. For each participant, the experimental software was programmed to select images randomly for non-target and target roles in the respective blocks from all images in the "nature" and "built" categories as determined by the results of the categorization task described above. Thus, two participants would not necessarily see all of the same images by the end of the experiment. The second half of participants received these blocks in the opposite order. Images were shown for 1,000 ms followed by a 500 ms fixed-cross inter-stimulus interval (**Figure 2**). In between blocks, a 45 s rest occurred.

ERP Analysis

For all ERP analysis the grand mean was taken across standard and target epochs. The p3 analysis window was defined as 200–400 ms (Rozenkrants and Polich, 2008). P300 amplitude was measured at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 from base to peak. P3 was calculated by taking the percent change of the p3 window relative to the ISI. This was then aggregated to calculate the grand means across channels. Mean peak amplitudes were used to derive the p3 across all participants for each condition. A 3-way repeated measures ANOVA for Environment (natural and built) × Stimulus (target and non-target) × Channel (14 channels) was conducted on p3 mean amplitude. A planned comparison excluding the Stimulus factor was also conducted in order to further isolate effects specific to Environment in the different Stimulus conditions. The LPP was defined as the mean amplitude at 550–930 ms after the target stimulus was presented (MacNamara et al., 2011). An initial 3-way repeated measures ANOVA (rmANOVA) for Environment (natural and built) × Stimulus (target and non-target) × Channel (14 channels) was also conducted on LPP mean amplitude. Achieved power ($1 - \beta$) was 1.00. Statistical analyses were performed in JASP (JASP Team, 2016). Analysis of variance (ANOVA) methods were used for group level comparisons. To correct

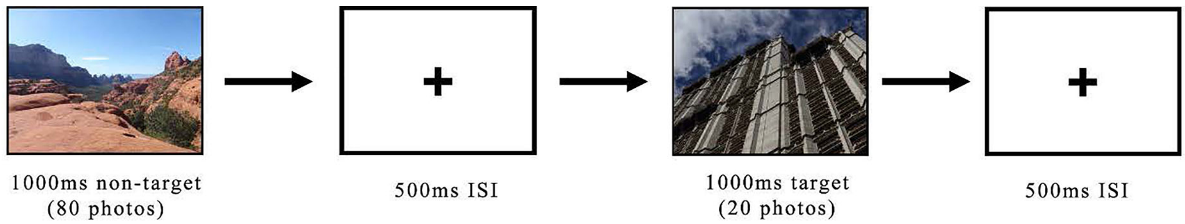

FIGURE 2 | Images were shown for 1,000 ms followed by a 500 ms fixed-crossed inter-stimulus interval. In between blocks, a 45 s rest occurred.

for sphericity violations, Greenhouse–Geisser was applied for all ANOVA comparisons.

RESULTS

Behavioral Results: Restorativeness Ratings and Categorical Preferences

Perceived restorativeness averages of the two environmental categories were compared using an independent samples *t*-test. The natural images (M = 6.48, SD = 0.94) were rated as more restorative than the built images [M = 5.64, SD = 1.12; $t(307.675) = 7.732$, $p < 0.001$, $d = 0.88$]. Natural images were expectedly rated higher on fascination [$t(312.204) = 8.599$, $p < 0.001$, $d = 0.97$], being away [$t(305.266) = 10.844$, $p < 0.001$, $d = 1.24$], extent [$t(316.204) = 16.863$, $p < 0.001$, $d = 1.89$], and compatibility [$t(304.169) = 8.637$, $p < 0.001$, $d = 0.99$]. Notably, natural images were unexpectedly rated lower than built on coherence [$t(306.882) = -15.634$, $p < 0.001$, $d = 1.78$]. The assumption of equal variances was not met for the comparisons of overall restorativeness, being away, fascination, extent, and compatibility. Thus, test statistics accounting for this violation have been reported; however, this assumption was met for the coherence comparison, and values for that test are thus unadjusted. For descriptive statistics by category for each restorativeness subcomponent, see **Table 1**.

TABLE 1 | Mean ratings by restoration subcomponent and environmental category.

Subcomponent	Category	Mean	*SD*
Fascination	Nature	7.33	1.29
	Built	6.07	1.51
Coherence	Nature	3.7	1.33
	Built	6.03	1.59
Extent	Nature	7.36	1.22
	Built	5.05	1.41
Being away	Nature	7.43	1.45
	Built	5.61	1.75
Compatibility	Nature	6.56	1.11
	Built	5.45	1.34
Preference	Nature	5.48	1.72
	Built	4.74	2.03

Preference is not considered a subcomponent of attention restoration.

A significant difference for preference between natural (M = 5.48, SD = 1.72) and built (M = 4.74, SD = 2.03) images was also revealed [$t(309.599) = 3.755$, $p < 0.001$, $d = 0.43$]. The assumption of equal variances was also not met for this comparison, with built images having significantly greater variance in preference than natural images (F-max = 1.39, $p < 0.05$), so the adjusted statistics are reported above.

ERP Results

p3 Results

After conducting the analysis along p3 mean amplitude, we found no significant interaction effects between Environment × Stimulus × Channel. A significant main effect for Channel was found [$F(2.462,145.25) = 162.37$; $p < 0.001$; $\eta_p^2 = 0.733$, $1-\beta = 0.99$], but no significant differences were found for Environment or Stimulus. A planned comparison excluding the Stimulus factor was also conducted in order to further isolate effects specific to Environment in the different Stimulus conditions, but no effect of Environment was found. Thus, no oddball effect of the 80/20% categorical frequency presentation scheme on attentional resources was shown. We failed to see a significant oddball effect for p3 [$F(1,59) = 0.135$; $p = 0.715$].

LPP Results

A significant main effect for Channel along LPP mean amplitude was revealed [$F(1.97,116.25) = 50.845$; $p < 0.001$; $\eta_p^2 = 0.463$] as well as a significant interaction for Environment × Channel [$F(4.36,257.34) = 4.36$, $p < 0.01$, $\eta_p^2 = 0.07$], which indicated a difference in polarity between frontal channels and posterior channels (**Figures 3**, **4**). Two separate 3-way rmANOVA were conducted on these two areas to compensate for polarity differences, and p-values were subsequently Bonferroni corrected. In frontal channels, a significant main effect for Environment was found [$F(1,59) = 11.12$; $p < 0.005$; $\eta_p^2 = 0.16$], indicating a greater LPP mean amplitude for built environments than natural environments [$t(59) = 3.34$; $p < 0.005$]. A Bayesian rmANOVA was also conducted, indicating strong support in favor of built environments eliciting greater LPP activity than natural environments (BF_{10} = 28.08; posterior probability: 96.56%; **Figure 5**). In posterior channels, a significant main effect for Environment was also found [$F(1,59) = 11.12$; $p < 0.005$; $\eta_p^2 = 0.16$], indicating a greater LPP mean amplitude for built environments than natural environments [$t(59) = 3.34$; $p < 0.005$]. A Bayesian rmANOVA was also conducted,

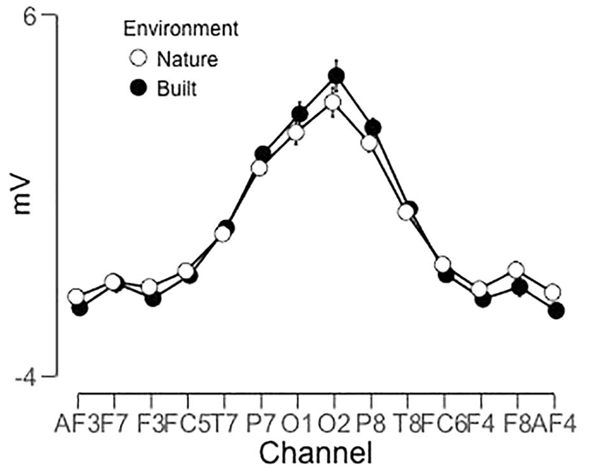

FIGURE 3 | Environment × Channel interaction showing difference in polarity between posterior and frontal channels [$F(4.36,257.34) = 4.36$, $p < 0.01$, $\eta_p^2 = 0.07$].

indicating support for built environments eliciting greater LPP activity than natural environments ($BF_{10} = 2.32$; posterior probability: 69.88%).

DISCUSSION

This study was designed to investigate, with ERP methodology and a passive oddball paradigm, whether viewing natural versus built environments correlates with distinct electrophysiological patterns. Unlike previous, primarily behavioral investigations, this study utilized temporally sensitive electrophysiological measures to examine potential differences in neural responses while viewing natural versus built environments. Our findings indicate lesser LPP amplitude and faster LPP recovery time when the non-target stimuli were those of natural environments versus built environments. Data suggest that participants perceived natural scenes as more pleasant than built scenes. Results also suggest that, in addition to explicit behavioral categorization, there may be an implicit categorization of natural and built environments that can be revealed through distinct physiological signatures. The current results leave open the question of whether stimuli were implicitly categorized as a function of naturalness, restorativeness, or both. Future studies should experimentally distinguish between these stimulus constructs.

Subjective ratings revealed greater perceived restorative potential for natural images than for built images. This finding is consistent with previous empirical studies of environmental imagery (Berto, 2005; Berman et al., 2008). While we did not collect self-report ratings of image emotional valence, we did find that preference was greater for natural environments than built. This suggests more positive association with natural images compared to built images when behavioral preference is explicitly measured. Given that previous research has found restorative environments to also be more explicitly preferred (Berto, 2005; Aspinall et al., 2013), it is suspected that the greater perceived restorative potential of the nature images used in this study underlies participants' demonstrated greater implicit preference for them. Further, some research has begun to explore the basic visual characteristics of natural scenery that may underlie the cognitive and emotional benefits of this scenery. For example, similar to Aspinall et al. (2013) findings of greater alpha wave activity when viewing natural scenery, Hägerhäll et al. (2015) found that viewing statistical fractals – the type of repeating visual patterns characteristic of natural scenery – correlated with greater alpha wave activity compared to exact fractal patterns – those characteristic of human architecture. As alpha activity is associated with a wakeful relaxed state and attentiveness, it may be that the same visual characteristics facilitating attention restoration may implicitly cue scene category.

Convergent, implicit electrophysiological evidence of this association derives from the lesser LPP activation found while viewing greater frequencies of natural compared with built images. In previous research, lesser LPP amplitude for valent stimuli has been indicative of greater perceived pleasantness (Hajcak and Nieuwenhuis, 2006; Hajcak and Olvet, 2008; MacNamara et al., 2011) as well as implicit and explicit categorization processes (Ito and Cacioppo, 2000). Since viewing natural scenes correlated with lesser LPP amplitude when compared to built scenes in the current study, it is plausible that natural scenes are more emotionally valent, and particularly more pleasant, than built scenes, even when viewed passively with no explicit instructions for categorization.

Late positive potential differences in response to viewing natural versus built stimuli were more apparent over frontal sensor sites than parietal or occipital sites (which showed significance, but with weaker consistency as determined by Bayesian analyses). Liu et al. (2012) LPP-BOLD coupling revealed between-category (pleasant, neutral, and unpleasant) differences in LPP amplitude, BOLD activity, and recruited neural substrates. These substrates' level of contribution to LPP modulation was also valence-specific. In the context of previous findings, we take the significant difference in LPP amplitude to indicate potential differences in perceived valence between natural and built scenes. However, LPP's being evoked by mere arousal, rather than also being moderated by valence, is debated, as cognitive neuroscientific conclusions are inherently prone to reverse inference (e.g., Hajcak and Nieuwenhuis, 2006; Poldrack, 2011). In fact, research has shown the effects of arousal and valence on LPP to be difficult to tease apart, though some differences in return to baseline have been found between high-arousing unpleasant images and pleasant images (O'hare et al., 2017).

A recent review by Hajcak and Foti (2020) concluded that even more so than arousal, LPP may likely be modulated specifically by motivational significance. This significance is that which facilitates approach and avoidance responses to stimuli, whether task relevant or not. Thus, it is plausible that the LPP from the current EEG sample correlates with such responses to both natural and built stimuli. Further, Gable and Adams (2013) found that paradigms with a long stimulus duration (e.g., 1,000 ms) elicit a more protracted p3, similar to the LPP elicited in an emotional viewing task, while oddball paradigms with a short

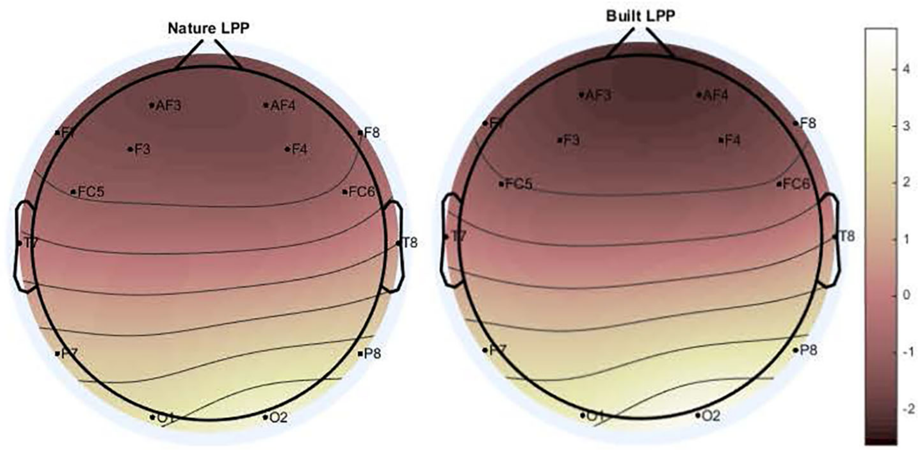

FIGURE 4 | Main effect of Environment indicates natural stimuli elicit lesser LPP mean amplitude than built stimuli across all channels [$F(1.97,116.25) = 50.845$; $p < 0.001$; $\eta_p^2 = 0.463$]. Differences in frontal and posterior channel polarity were resolved by dividing subsequent analyses into frontal channels only (AF3, F3, F7, FC5, FC6, F4, F8, and AF4) and posterior channels only (T7, P7, O1, O2, P8, and T8).

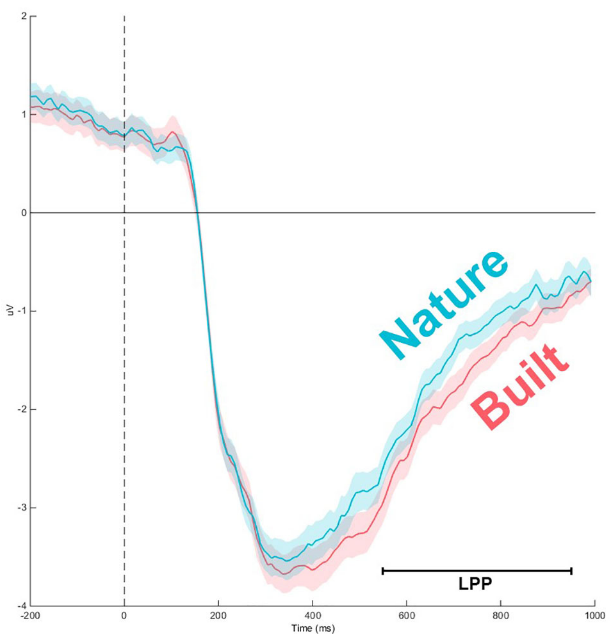

FIGURE 5 | Event-related potentials time course for frontal channels (averaged). Main effect of Environment indicates natural stimuli to elicit lesser LPP mean amplitude than built stimuli in frontal channels [$F(1,59) = 11.12$; $p < 0.005$; $\eta_p^2 = 0.16$]. Error shading represents 95% confidence interval.

stimulus duration (e.g., 200 ms) elicited a more typical p3. That stimuli in the current study were displayed for 1,000 ms, but the p3 analysis window was restricted to 200–400 ms, could explain the lack of p3 differences found between conditions.

This lack of a significant oddball effect in the current study, though surprising, may also be due to the use of a passive task. Given that the standard and target images were determined at the category level, perhaps an *active* oddball task, in which participants received instructions to specifically search for, and respond to, various exemplars of the low frequency target category, using the current stimuli, may have shown p3 differences, and thus an oddball effect—though this remains to be tested. In combination with the passive nature of the task, another limiting factor with respect to examining the p3 may have been within-category stimulus diversity: the large number of unique images within each category. The p3 component is traditionally studied using one exemplar of a category in each of the target and non-target roles (Polich, 2003; Rozenkrants and Polich, 2008). A design incorporating within-category stimulus homogeneity may more directly elicit a p3 component. Another limitation is that, given our stimulus categorization thresholds (>60% = natural, <40% = built), the lack of a significant p3 finding could also be due to the inclusion of environmentally heterogeneous images. For example, a natural image that was categorized as "natural" by 61% of the categorization sample may still contain a substantial number of built environment features. Operationalizing the natural and built categories at the chosen thresholds was necessary, though, to ensure sufficiently large stimulus sets in the current study. Furthermore, within-environment stimulus diversity was necessary in order to draw category-level conclusions for environment. Previous behavioral studies of natural versus built environments have also employed diverse stimulus sets (Berto, 2005; Berman et al., 2008; Roe et al., 2013; Pasini et al., 2014), prompting the neural comparison design reported herein. Questions concerning potential methodological limitations, however, should be addressed in future research.

Future Directions

The current results leave open the question of whether stimuli were implicitly categorized as a function of naturalness, restorativeness, both, or possible correlating low-level visual features (Kotabe et al., 2017); the variables correlate in the current design. Natural stimuli within this study were rated higher in four of the five components of ART, indicating natural environments in this study to be more restorative than built environments. Since the design of this study relies on a passive task measuring implicit categorization, it is possible that components of ART requiring greater implicit (bottom-up) processing are most critical in determining categorical differences in restoration. An example of one such component could be *fascination*, or how an environment captures exogenous attention. In the current study, though, we cannot separate out the different components of ART for each given stimulus in order to accurately assess whether the differences are truly due to restoration as opposed to the 'naturalness' of environmental categories (e.g., Scopelliti et al., 2019). Image statistics and the time course of visually processing natural vs. non-natural scenes may also drive the implicit categorization of these two environment types. The fractal structure in natural scenes may be more quickly and easily processed than the straighter structure in man-made scenes, and contextual cues to category may derive from quickly established global action (affordance) or function related properties of environments—rather than merely segmented, local objects and parts (e.g., Torralba and Oliva, 2003; Green and Hummel, 2004; Greene and Oliva, 2006, 2009; Oliva and Torralba, 2006, 2007). Future research should further measure and characterize the statistical properties in scenes to help elucidate mechanisms underlying the current findings (e.g., Geisler, 2008). Future research should also further address neural correlates with natural versus built environments using stimuli presented in modalities other than vision. Previous studies suggest that organisms may judge soundscape environments as pleasant based on perceived indicators of safety – though in contrast to the visual processing discussed above, this type of auditory processing is subcortical (e.g., Andringa and Lanser, 2013; van den Bosch et al., 2018). It would be interesting if across modality, findings converged to show that organisms more rapidly and easily categorize natural environments as safe and therefore also as more pleasant.

Although participant ratings of the stimuli used in this study revealed natural scenes to be more restorative overall than built scenes, natural scenes were surprisingly lower than built scenes along the 'coherence' component. To clarify this result, replications using these stimuli should collect negative- and positive-specific valence ratings. Also, further ratings using the PRS-short should be collected to ensure that the direction of the coherence difference reported herein is not spurious. It is also possible that 'coherence' was interpreted by participants differently than it has been defined within ART; perhaps, for example, participants rated coherence lower in natural scenes since unlike built environments, they are not designed for some human-driven purpose. Finally, future research should explore correlations between specific ART components and positive and negative valence, as well as performance on directed attention tasks. It may be that some ART components - expectedly, being away and compatibility – may contribute more to positive valence of a scene while others, such as fascination, extent, and coherence, are more strongly related to replenishment of attentional resources as suggested by previous ART research. Although the work presented here is only an initial exploration, understanding the role of positive experience within attention restoration—including from a neural perspective – is a ripe area for future investigation. A neural methodological perspective will help us understand more completely the various health benefits humans can accrue from exposure to natural environments.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Utah State University IRB. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SM, NW, AP, AH, JC, TL, and KJ wrote the manuscript. SM, NW, AP, AH, TL, and JC collected the data. SM, AH, NW, AP, and JC performed the data analysis. SM, NW, and KJ conceptualized the study.

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Promoting Healthy Decision-Making via Natural Environment Exposure: Initial Evidence and Future Directions

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Research within psychology and other disciplines has shown that exposure to natural environments holds extensive physiological and psychological benefits. Adding to the health and cognitive benefits of natural environments, evidence suggests that exposure to nature also promotes healthy human decision-making. Unhealthy decision-making (e.g., smoking, non-medical prescription opioid misuse) and disorders associated with lack of impulse control [e.g., tobacco use, opioid use disorder (OUD)], contribute to millions of preventable deaths annually (i.e., 6 million people die each year of tobacco-related illness worldwide, deaths from opioids from 2002 to 2017 have more than quadrupled in the United States alone). Impulsive and unhealthy decision-making also contributes to many pressing environmental issues such as climate change. We recently demonstrated a causal link between visual exposure to nature (e.g., forests) and improved self-control (i.e., decreased impulsivity) in a laboratory setting, as well as the extent to which nearby nature and green space exposure improves self-control and health decisions in daily life outside of the experimental laboratory. Determining the benefits of nearby nature for self-controlled decision-making holds theoretical and applied implications for the design of our surrounding environments. In this article, we synergize the overarching results of recent research endeavors in three domains including the effects of nature exposure on (1) general health-related decision-making, (2) health and decision-making relevant for application to addiction related processes (e.g., OUD), and (3) environmentally relevant decision-making. We also discuss key future directions and conclusions.

Keywords: environment, delay discounting, impulsivity, addiction, decision-making, nature, conservation, sustainability

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INTRODUCTION

For decades environmental psychologists have extensively documented the multiple benefits to humans resulting from nature exposure. Although additional replication and extensions are needed, these benefits include a plethora of physiological and psychological improvements to human health including reduced recovery time following surgery, health improvements in patients with cancer (e.g., increased expression of anti-cancer antibodies), reduced hypertension, reduced stress, and increased happiness (Ulrich, 1984; Li et al., 2008; Mao et al., 2012; Thompson et al., 2012;

White et al., 2013; see Twohig-Bennett and Jones, 2018 for a review and meta-analysis of health outcomes and greenspace exposure; see Houlden et al., 2018, for a review of the relationship between greenspace and mental wellbeing in adults). There is also recent evidence that suggests nature exposure could be a beneficial adjunctive treatment option in addition to traditional pharmacotherapy for individuals who suffer from disorders associated with lack of impulse control (e.g., addiction-related disorders, evidence from various fields reviewed in detail below). Despite these well-documented benefits of nature exposure to human health, we as humans continue to degrade our natural environments. The most critical environmental and public health crises that contribute to degradation of natural spaces (e.g., species extinction, forest degradation, accelerated climate change resulting from anthropogenic influence, millions of premature deaths annually resulting from emissions/poor air quality) are a direct result of human decision-making and behavior (Chivian and Bernstein, 2008).

For example, despite climate scientists' account of current emissions as "dangerous to extremely dangerous" (Anderson and Bows, 2011), anthropogenic influenced global carbon emissions have surpassed the worst scenarios predicted by the Intergovernmental Panel on Climate Change (Boden and Blasing, 2010). Relatedly – poor air quality resulting from emissions is one of the leading causes of premature death worldwide – with nearly seven million mortalities occurring globally each year (World Health Organization [WHO], 2014, 2015, 2017). The direct contribution of human behavior (e.g., emissions from industries, factories, extensive private car use, air travel) in driving negative environmental outcomes (e.g., poor air quality, climate change) and resulting detrimental human health consequences (e.g., premature death) are well-documented and highly publicized.

In this manuscript we focus on the effects of nature exposure on decision-making processes relevant for human and environmental health. We will briefly synthesize findings and discuss future directions across key domains (1) at the intersection of nature exposure and human health related decision-making, (2) the potential for novel extensions combining health benefits and decision-making benefits of nature exposure to addiction research, and (3) the effects of nature exposure on environmentally relevant decision-making. The present manuscript is not an exhaustive literature review, but rather designed to briefly emphasize key discussion points and identify promising future directions related to nature exposure.

NATURE EXPOSURE, HEALTH, AND HEALTH RELATED DECISION-MAKING

Our work has primarily focused on determining mechanisms that influence decision-making to result in healthier decisions for both humans and ecosystems. For example, decades of research have demonstrated that exposure to natural (e.g., forests, lakes) as opposed to built (e.g., cities, buildings) environments reduces stress (Ulrich et al., 1991; Thompson et al., 2012), enhances attention (Faber Taylor et al., 2001; Berto, 2005), and improves mood (Bowler et al., 2010). Beyond these psychological benefits, biodiversity is also crucial to our physical health for medicines, medical research, combating infectious diseases, and food production. Adding to the research on health and cognitive benefits of natural environments, this team's research is among the first to show that not only cognition, but also *behavior, choice and delay discounting* are influenced differently as a function of natural versus built environmental exposure. Delay discounting refers to the decrease in value of an outcome with delay to receiving that outcome (Mazur, 1987). A delay discounting task evaluates choices between smaller sooner and larger later outcomes across a range of delays (e.g., $50 now or $100 in 5 years). A consistent pattern of choice of the smaller sooner outcomes is thought to represent relative "impulsive" decision-making. Delay discounting is one behavioral measure of "impulsivity." Impulsivity has a number of different meanings (e.g., inability to delay gratification) and can be measured in different ways. High rates of delay discounting (i.e., "impulsive" decision-making) are associated with a host of maladaptive behaviors including cigarette smoking, opioid abuse, and gambling (see Odum et al., 2000; Dixon et al., 2003; Kirby and Petry, 2004; Mitchell, 2004a,b). Delay discounting, therefore, may represent a target for intervention for health-relevant behavioral processes. At present delay discounting is thought to be one of the most valuable decision-making predictors of human behavior both within the laboratory and real-world decision-making contexts (Chabris et al., 2008).

Some evidence shows choices in other delay of gratification tasks are more "self-controlled" (i.e., less impulsive) with exposure to nature as opposed to built environments. Faber Taylor et al. (2002) demonstrated that among children living in the inner city, the more natural a girl's view from home was, the more "self-controlled" she was on a modified version of the classic marshmallow task (this same relation was not true for boys). van der Wal et al. (2013) also found that visual exposure to photographs of natural scenes on a computer screen resulted in less impulsive decision-making in a delay discounting task than photographs of built scenes. In a follow-up experiment, similar results were obtained when participants walked through either natural landscape environments or built landscape environments and then chose between receiving money now or in the future. Our lab has also shown that individuals visually exposed to natural environments exhibit more self-controlled decisions, while individuals exposed to built environments demonstrate more impulsive decisions in a monetary delay-discounting task (Berry et al., 2014; see **Figure 1**; Berry et al., 2015), and this effect may be related to expanded time and space perception (Berry et al., 2015; Repke et al., 2018).

Specifically, elongated time perception resulting from visual exposure to natural environments, could be a key mechanism underlying increased self-control with exposure to nature (Berry et al., 2015). It is possible that an expanded time perception window may facilitate bridging the gap between current decisions and future consequences of those decisions. The extent to which nearby nature and green space exposure improves self-control and health decisions in daily life outside of the experimental laboratory, however, has remained unexamined until recently, but holds applied implications for the design of our

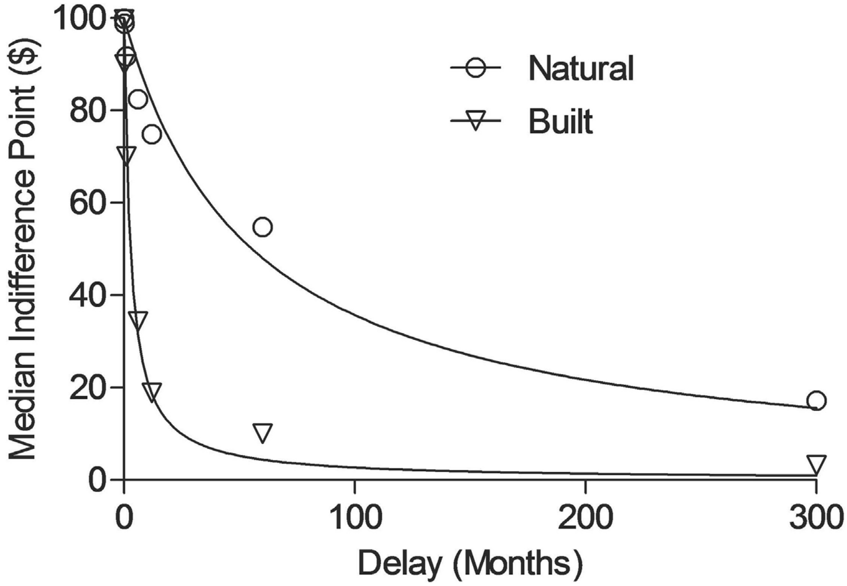

FIGURE 1 | In this study, participants viewed photographs of either natural or built scenes on the computer screen prior to engaging in the delay discounting task and time perception task (see Berry et al., 2015 for additional details). The data points represent median indifference points (i.e., the subjective value) as a function of delay (months) for natural (circles) and built (triangles) conditions. Lines show the best fit of the non-linear regression equation to the median indifference points (see Berry et al., 2015 for additional details). The "steeper" curve shows more impulsive decision-making (built) and the shallower curve shows more "self-controlled" decision-making in the delay discounting task.

surrounding environments to promote healthy decision-making for individuals and surrounding ecosystems, as well as happiness and general well-being. We recently conducted two studies to test a new model linking the health benefits of nature exposure to reduced impulsivity in decision-making. We determined in a real world national United States sample, participants' geospatial proximity to nature by quantifying the natural land cover surrounding participants' home addresses using remotely sensed data. Measures of nature accessibility predicted reduced "impulsive" decision-making in a delay discounting task, and also showed significant indirect effects through impulsive decision-making on depression and anxiety measures and general health and well-being. We paired this study with a laboratory-based paradigm and found that visual exposure to nature expanded perceptions of space, and while the indirect effects of nature exposure through space perception on impulsive decision-making did not meet conventional standards of significance ($p < 0.10$), the pattern was consistent with hypotheses. This combination of ecologically valid and experimental methods offers promising support for an impulsivity-focused model explaining the nature–health relationship (Repke et al., 2018).

EXTENDING CURRENT APPLICATIONS OF NATURE EXPOSURE AND HEALTH DECISION-MAKING TO ADDICTION-RELATED RESEARCH

Further extending and interweaving the above health-relevant decision-making models directly to addiction research, we recently proposed nature exposure as an adjunctive treatment option for opioid use disorder (OUD) in addition to traditional agonist pharmacotherapy treatment (e.g., methadone; Berry, under review). From 2002 to 2017 in the United States alone, deaths from opioid overdose have more than quadrupled (National Institutes on Drug Abuse, 2018). Relatedly, pain represents the leading cause of disability in the United States, affecting more Americans than diabetes, heart disease, and cancer combined (National Institutes of Health, 2019). The demand for opioid medication to effectively treat pain has contributed to the surging opioid crisis. More than 100,000 people begin opioid maintenance treatment (OMT) annually (Substance Abuse and Mental Health Services Administration [Samhsa] and Center for Behavioral Health Statistics and Quality, 2014), which is the standard of care. However (and paradoxically), OMT patients often experience or develop a heightened sensitivity to pain (hyperalgesia; Dunn et al., 2015), and have high rates of stress and affective and anxiety-related comorbidities (Hyman et al., 2007; Sinha, 2008; Gros et al., 2013). These conditions are interactive with other behavioral and environmental correlates of opioid and other substance use disorders including "impulsive" decision-making (e.g., harmful opioid use is associated with increased delay discounting), and a lack of alternative (i.e., substance free) and social (e.g., strong friendships and/or romantic relationships) reinforcement.

A promising, novel adjunct treatment option that could preserve the benefits of OMT and simultaneously improve pain management, decrease stress and anxiety, reduce behavioral correlates associated with OUD (e.g., "impulsivity" in delay discounting, or real world decision-making underscoring delay discounting processes in every day life, such as a choice between an immediate drug high over longer term healthy family relationships), as well as enhance alternative and substance free sources of reinforcement, may be exposure to nature and/or green space. Green light – similar to that in green spaces – has analgesic properties and reduces experimental pain in animal models (Ibrahim et al., 2017), an effect which appears to be mediated through the visual and opioid systems, and more. This effect has cross-species generality, showing that green light reduces pain intensity of migraines (Noseda et al., 2016), and nature scene murals placed at the bedside (as well as nature sounds in the background) during a flexible bronchoscopy procedure reduced self-reported pain compared to a control condition. This effect remained after controlling for age, gender, race, health status, and medication doses (Diette et al., 2003).

As discussed previously, research also shows exposure to nature (including green space) decreases anxiety, stress, and depression, which are common comorbid conditions among individuals with opioid use and other substance use disorders (Kushner et al., 1990, 2008; Koob and Schulkin, 2019). Access to green space and nature is also associated with reductions in craving of various substances (Martin et al., 2019). Given the strong relations between delay discounting and harmful opioid use that could serve as a potential therapeutic target, we reiterate that visual and actual exposure to natural environments also decreases "impulsive" decision-making in delay discounting tasks (e.g., van der Wal et al., 2013; Berry et al., 2015). Finally, individuals living farther away from recreational outlets (including parks and green space) and have less access to pleasant activities have higher rates of substance use, including prescription opioid use (Leventhal et al., 2015). Taken together, nature exposure could serve as a promising adjunctive treatment option for opioid abuse. However, little if any systematic research exists to inform this topic.

NATURE EXPOSURE AND ENVIRONMENTALLY RELEVANT DECISION-MAKING

In additional to personally relevant health decision-making, exposure to nature (either simulated or actual) may also promote environmentally relevant decision-making. Researchers have previously discussed the potential of nature exposure itself as a pro-environmental behavior trigger through various mechanisms (Annerstedt van den Bosch and Depledge, 2015). Zelenski et al. (2015) showed that people engage in future-oriented decisions that help to promote cooperation, conserve resources and behave more sustainably for themselves and team members in a public goods game after viewing videos of natural versus built environments These findings suggest that exposure to natural as opposed to built environments are not only beneficial for cognition, stress, and mood, but might also lead to healthier *behaviors* for individuals and ecosystems via improved global decision-making processes (i.e., decision-making across more than one domain, for example, money and health related decision-making, see Odum, 2011). These results have important implications for how we structure and design our environments (e.g., more green spaces in cities to promote future-oriented decision-making), as well as the impetus to preserve natural environments for human and ecological well-being.

Delay discounting, which has been proposed as a behavioral measure of sustainability (more sustainable associated with more "self-controlled" decision-making) and could serve as a global target for intervention. Few studies, however, have directly examined this concept in terms of environmentally relevant decision-making. Hardisty and Weber (2009) examined delay discounting of hypothetical financial, air quality, and health gains and losses scenarios across two delays. Within-subject analyses revealed that individuals who discounted gains steeply ("impulsively") in one realm (e.g., monetary) also discounted gains steeply ("impulsively") in other realms (e.g., air quality, health) and vice versa (see also Meyer, 2013; Johnson and Saunders, 2014; Kaplan et al., 2014; Richards and Green, 2015 for examples of environmental commodity discounting/support for long-term conservation goals). Extending this line of work Berry et al. (2017a,b) showed that mechanisms similar to those driving decisions for monetary outcomes might also be driving decisions about air quality (and possibly other ecological outcomes). This line of research lends support to targeting the same underlying mechanisms to facilitate reduction of delay discounting ("impulsivity") on a global scale (see Odum, 2011). Therefore, reductions in monetary delay discounting as have been previously shown through various techniques (e.g., exposure to nature, van der Wal et al., 2013; Berry et al., 2015; future episodic thought, Peters and Büchel, 2010; for a review see Koffarnus et al., 2013) may also reduce delay discounting of air quality or other ecological commodities. Reducing delay discounting of environmental commodities could hold relevance for real-world environmentally relevant decision-making. We have further combined the above lines of research to determine if exposure to natural environments also decreases "impulsive" air quality choices. Evidence suggests that individuals respond in a more self-controlled way for ecological decisions related to air quality with exposure to natural as opposed to built environments (Berry et al., 2019). These results were associated with expanded space perception as previously shown (e.g., Repke et al., 2018). Although an initial foundation, this research still represents an area that has much opportunity for growth.

CONCLUSION

More research is needed to further understand mechanistic drivers of behavior change with exposure to natural environments, and to test and expand these findings beyond laboratory settings. Exposure to natural environments provides a myriad of psychological benefits, and may also be useful as adjunctive treatments for addictive disorders (specifically OUD). Beyond personal health and wellness benefits, exposure to nature may also prove valuable for environmentally relevant decision-making.

As previously noted, there have been too few systematic experiments examining the potential of nature exposure as an adjunctive treatment for addiction (e.g., OUD) and disorders associated with lack of impulse control. This is also true of environmental decision-making in the context of nature exposure and actual behavior change outside of laboratory settings (i.e., not self-report data, although of course self-report data can be informative in different ways; please see Steg and Vlek, 2009 for review and commentary). Further, many of the studies reviewed here (and in the literature) focus on short-term effects. There is a need for longer-term and longitudinal studies to understand sustained benefits of nature exposure on psychological, health, decision-making and environmental outcomes. Experimental analysis of behavior might hold useful tools for identifying factors that increase or decrease discounting of environmental commodities – which could help shift individual and societal decision-making toward both long-term conservation and health-oriented behaviors. Of primary importance will be determining whether similar underlying processes drive environmental decision-making as monetary decision-making; and if these processes do share underlying mechanisms, reduction of impulsivity may be approached on a more global scale (see Odum, 2011 for discussion), holding implications for health, treatment of disorders associated with lack of impulse control such as OUD, and environmentally relevant decision-making.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

MB synthesized the literature and wrote the original draft of the manuscript. All authors contributed to the conceptualization and review and editing of the manuscript draft.

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Conceptualizing the Human Health Outcomes of Acting in Natural Environments: An Ecological Perspective

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Human-nature interactions have been presented as important for promoting and sustaining wellbeing and health benefits. Research has shown that pictures of nature, interacting with nature, physical activity in nature, immersion in nature and even feeling connected to nature can improve health. While considerable research supports this notion that nature can have positive health impact, theoretical and conceptual frameworks that help explain *how* the natural environment provides benefits to human health and wellbeing have proved limited. In extreme cases, theoretical approaches reinforce a problematic notion where nature is viewed as a separate entity, as a treatment to be taken as prescribed to remediate health problems that arise. Such approaches are limited as they fail to address how beneficial person-nature relations may be captured in interventions. There is a need for a deeper understanding of the processes underlying the observed benefits of the person-nature link in order to design effective research and interventions. It is especially important to consider the implications of research on person-nature relations for people living in urban contexts. In this paper, we present an ecological perspective building on James Gibson's conceptualization of human behavior. Specifically, we outline a framework that emphasizes the person-environment system as the most appropriate scale of analysis. We present three relevant concepts from the ecological approach: form of life, affordances and niche construction, as helpful for appreciating how acting in natural environments might benefit human health and wellbeing. This approach urges policy makers and urban designers to rethink environmental designs to provide and support a landscape of affordances that makes use of the richness of natural environments.

Keywords: ecological psychology, affordances, niche construction, form of life, natural environments, health and wellbeing

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INTRODUCTION

There is now a robust body of evidence suggesting that the relationship between human beings and nature can support positive health and wellbeing. Pictures of nature, interacting with nature, physical activity in nature, immersion in nature and feeling connected to, or part of, nature can improve health (Kaplan and Kaplan, 1989; Hartig et al., 1991; Ulrich et al., 1991; Kuo, 2001; Peacock et al., 2007; Tsunetsugu et al., 2009; Ryan et al., 2010; Roe and Aspinall, 2011; Berman et al., 2012;

Wolsko and Hoyt, 2012; Gladwell et al., 2013; Berto, 2014; Passmore and Howell, 2014; Martyn and Brymer, 2016; Menatti and Casado da Rocha, 2016; Yeh et al., 2016; Lawton et al., 2017; Schweitzer et al., 2018). As a consequence, there is an increased interest in how to design nature-based activities and environments to enhance human and planetary health and wellbeing (Brymer et al., 2014; Brymer and Davids, 2016; Davids et al., 2016; Yeh et al., 2016, 2017; Houge Mackenzie and Brymer, 2018). Despite the extensive practical work and empirical research demonstrating the positive relationship between experiences with nature and enhanced health and wellbeing, the conceptual and theoretical underpinnings of *how* person-natural environment relations can support health and wellbeing is limited (Bowler et al., 2010; Brymer et al., 2014; Brymer and Davids, 2016; Araújo et al., 2019a). Here, we argue that, for the most part, this deficit has emerged because traditional theoretical perspectives view nature and people as distinct and separate entities (Heft, 2012). Such a dualism has promoted a biased understanding of human behavior which is unlikely to help further an understanding of the processes supporting human-nature relations, or support effective health-focused research and intervention designs that are based around human-nature relations. In this paper, we draw on an ecological perspective building on Gibson's (1979) work. Specifically, we propose a "transactional" framework that emphasizes the animal-environment relationship as the appropriate scale of analysis for understanding the health benefits (human and nature) from the human-nature system. We present three particular concepts from this ecological approach - form of life, affordances and niche construction - as helpful for appreciating how human-nature interactions might benefit health and wellbeing.

TRADITIONAL THEORIES EXPLAINING THE NATURE – HEALTH AND WELLBEING RELATIONSHIP

Theoretical models explaining the relationship between nature experiences and health and wellbeing have predominately focused on explaining the mental health benefits gained from nature. The two main approaches emphasize either: 1. (physical) activity in nature; or 2. feeling connected to nature. For instance, Ulrich's Psychoevolutionary Theory (PET; Ulrich, 1981), also known as stress reduction theory, proposes that humans prefer natural environments that provide safety and resource availability (e.g., water, shelter and vegetation). Attention Restoration Theory (ART; Kaplan and Kaplan, 1989) proposes that everyday human experiences in urban societies are cognitively taxing, requiring high levels of sustained effortful attention. Conversely, nature provides opportunities to restore attention. Finally, Nature Connection theories, such as, Nature Connectedness (NC) and Nature Relatedness (NR; Cervinka et al., 2012; Capaldi et al., 2014; Zelenski and Nisbet, 2014), are based on an individual difference narrative in which wellbeing is correlated with emotional connection with the natural environment (Mayer and Frantz, 2004), conceived as a mental state.

While these approaches have made relevant contributions, critics have pointed to important limitations that have profound implications for understanding how nature might enhance health and wellbeing and for developing theory, research, policy and design (Menatti and Casado da Rocha, 2016). For the most part, traditional approaches emphasize an anthropocentric perspective which reinforces a notion of nature as separate from humanity, and in extreme cases, merely a resource, commodity or treatment (very much like a "pill") to be exploited for human benefit (van Heezik and Brymer, 2018). Critics have pointed out that, as a result, these approaches are not able to conceptualize the full range of health enhancing experiences from nature (Brymer et al., 2014; Araújo et al., 2019a) and, importantly, do not fully capture how the person-natural environment system supports health and wellbeing (Hartig et al., 2010; Bratman et al., 2012; Hartig and Jahncke, 2017; Brymer et al., 2020). Furthermore, the predominant anthropocentric focus underlying traditional approaches causes them to largely overlook the inherently multi-dimensional, embedded and embodied complexity of the relationship between humans and nature (Brymer et al., 2014; Conniff and Craig, 2016; Franco et al., 2017; Schweitzer et al., 2018; Araújo et al., 2019b). As a consequence, there is an over-emphasis on structural aspects of the form of nature as an entity, focusing on what nature looks like in terms of color and shape (Brymer et al., 2014). There is also an overemphasis on the individual, focusing on internal processes as the explanation for the person-environment link (Araújo et al., 2019a). More recently, studies examining experiences in nature (Park et al., 2007; Tsunetsugu et al., 2009; Lee et al., 2011; Roe and Aspinall, 2011; Schweitzer et al., 2018) have shown that outcomes may stem from a more ecological, embodied, transactional relationship with the natural environment. The relationship between humans and nature is more complex than traditional theories suggest (Brymer et al., 2019; see also Heft, 2013). In the following section, we present a transactional framework building on Gibson's (1979) ecological perspective; Ecological Dynamics. This framework which stems from a transactional worldview in which individuals are seen as goal-directed agents whose actions are ongoing and contingent upon a wide range of changing situational factors (Heft, 2012), emphasizes the mutuality of individual-environment relationships as an appropriate theoretical underpinning for understanding the health and wellbeing benefits from the human-natural environment system. Three particular concepts, emanating from the ecological perspective, are highlighted to exemplify the arguments: form of life, affordances and niche construction, suggesting how human-nature interactions might benefit health and wellbeing.

AN OVERVIEW OF ECOLOGICAL DYNAMICS

Ecological Dynamics is a framework that integrates key ideas stemming from ecological psychology and dynamical systems theory and applies them to deepen the understanding of health and wellbeing (Brymer and Davids, 2013, 2014, see Araújo et al., 2020, for a review). Ecological Dynamics has a foundation in the complexity sciences, conceptualizing the individual animal as a complex dynamic system (Kelso, 1995), composed of many interdependent, interacting subsystems or domains (e.g., physical, cognitive, social, emotional). The individual organism forms a part of the larger ecological system. This framework has been employed to interpret behavior in a variety of fields such as health, education, psychology, sport, outdoor education, adventure sports and environmental education (Brymer and Davids, 2013, 2014, 2016; Brymer et al., 2014; Sharma-Brymer et al., 2015; Clough et al., 2016; Davids et al., 2016; Yeh et al., 2016).

Ecological Dynamics takes the person-environment system to be the primary scale of analysis and refutes the dualist assumptions – central to the previously described traditional, interactional (or mechanistic) approaches (see Heft, 2012) – that underpin scientific notions, such as body and mind, or environment and animal. Instead, Ecological Dynamics promotes the holistic acceptance of embeddedness of a person and environment and mind and body (Brymer and Davids, 2013, 2014). The Ecological Dynamics approach further demands reassessment of an inherent "organismic asymmetry", the intrinsic bias for seeking explanations of human behavior and experiences based on internal mechanisms and referents, regularly promoted in psychological sciences (Dunwoody, 2006; Davids and Araújo, 2010). Behavior is explained as originating from a bounded, self-contained entity and with reference, primarily, to qualities or dispositional properties within an individual. For example, traditional personality psychology perspectives on human-nature relationships typically emphasize the role of specific individual characteristics (e.g., feelings of connection to nature), with little reference to the role of the environment in guiding behaviors. This biased tendency is avoided by considering the mutuality of the person-environment system. Rather than promoting an understanding of behavior as stemming from the mind, in the Ecological Dynamics approach, behavior emerges from the human-environment relationship, the behavior of an animal emerges from its embodiment and embeddedness in an environment.

Another aspect from the traditional environmental focus that can be seen to result from an interactionist (or mechanistic) worldview and is motivated by notions that certain characteristics of place, location and geography (such as Topophilia, place attachment and the notion of therapeutic landscapes) impact health and wellbeing (Dummer, 2008; Menatti and Casado da Rocha, 2016). From this mechanistic worldview, the individual is seen as a bounded and independent entity that exists among independent entities and their influences (Heft, 2012). It is through the interactions between the bounded individual and the bounded natural environment that health and wellbeing is impacted. Typically, this promotes a one-size-fits-all approach where certain environmental characteristics impact, like bouncing billiard balls, the health and wellbeing of the individual. This approach has led to assessments of a "dose response" effect, where exposure to natural environment is required to facilitate good health. The natural environment is treated as a metaphorical "pill" suitable for the treatment of all people from all backgrounds (van Heezik and Brymer, 2018). The environment is perceived as separate from the individual and acting on the individual (Menatti and Casado da Rocha, 2016).

In the context of providing a theoretical underpinning for the human-nature relationship and wellbeing, the Ecological Dynamics perspective takes the individual-environment relationship as the primary scale of analysis. The Ecological Dynamics approach further accepts the observation that individuals have bodies, exist in environments and are constrained by the interacting characteristics of both. Adopting the person-environment system as a scale of analysis for understanding the wellbeing outcomes of human-nature relationships would provide an opportunity to address individual activity and environmental differences that might help explain outcomes and provide a framework for research design.

To understand how this process may occur there are three key conceptual ideas worth highlighting within the Ecological Dynamics framework: *affordances*, *form of life* and *niche construction*. The notion of affordances originated in ecological psychology (Gibson, 1979) and refers to how the environment is perceived in behavioral terms (not in neutral terms like time and space), that is, what the environment offers for doing, and thus combining the nature of the environment with the nature of an individual (Gibson, 1979). In the context of agency, and for the purpose of understanding how the natural environment can motivate and shape health behaviors, affordances can be conceptualized as behavioral invitations offered by the environment, related to the particular capacities, skills and capabilities of the individual (Withagen et al., 2012). That is, in individual environment systems, the behavior which results from the individual-environment link is complex and dynamic; it is not an interpretation of the individual or a response to a stimulus, but an emergent property of this person-natural enviorment system. At any instance in time an innumerable amount of affordances is presented, and available for utilization by an individual. An environment described in terms of affordances changes the emphasis from a structural form description, neutral to the individual, to an active and functional description, in behavioral terms. For example, landscapes traditionally described in terms of color, height, esthetics and so forth can be deemed to consist of behavioral opportunities, such as climbable features, apertures, shelters, flat surfaces, textured or smooth surfaces, inclines, solid or liquid volumes, graspable surfaces, attached objects and so on (Brymer et al., 2014).

Affordances might also be related to cultural and social constraints (Brymer et al., 2014). An individual's capacity to actualize certain affordances can change over time and through the manipulation of environmental constraints. Importantly, for health and wellbeing, affordances do not always promote positive outcomes and can also invite unhealthy behaviors. For example, our modern-day environment is abounding with convenience – and related – affordances for sedentary and health-threatening behaviors. Think of how city infrastructure promotes car-use over walking or cycling, or how high street lay-out and advertising invite the consumption of fast food (Brymer and Davids, 2016). Conceptually, human beings are adapted to exploit the myriads of affordances available in the human-natural world relationships.

Inclusion and removal of certain of these affordances need to be carefully considered in relation to the serious risk of negative unintended consequences for health and wellbeing.

The form of life concept originates from Wittgenstein (1953) and describes how a specific group of human beings or other animals interacts in and with the world around them. That is, form of life describes both the potential and common affordances available in individual-environment systems. This might, for example, manifest as a social or cultural tendency or patterns of behavior (Rietveld and Kiverstein, 2014). For instance, for birds as a form of life, high trees afford shelter and launching pads for flying. However, for monkeys while the same trees might afford shelter, affordances for flying are not available to the monkey form of life. Conceptually, just as monkeys function best in environments appropriate for their adaptations (Gluck and Sackett, 1976), the human form of life is more likely to flourish in the presence of human health and wellbeing affordances.

The terms niche and niche-construction capture an often overlooked, but never-the-less, important aspect of the relevance (and primacy) of the animal-environment scale of analysis and how animal and environments evolve together. That is, both individual and environment are responsible for co-construction and design of affordances. The agency and influence of the individual (or group of individuals) is involved in constructing the everyday environment. Take the beaver that builds the dam in a place that is invited by the relationship between the animal and its environment. The availability of water features and trees appropriate for the particular beaver's capacities enhance affordances of a certain kind. In a similar vein, humans construct their environment for availability of specific affordances, such as a green park in the city. This co-designing notion extends the evolutionary idea that environments impact the animal, equipping the animal with action capabilities relevant for inhabiting a particular environment. In this way, niche construction supports animal agency and its impact on affordance perception, utilization, creation and destruction (Withagen and van Wermeskerken, 2010). Niche construction not only requires the utilization of affordances, it also consists of a change in the affordance layout. Hence, individuals often create and destroy affordances, with other individuals being exposed to these modified environments as new members of a group. Human beings are both molded by and mold their environment in non-random ways. Over time this mutual co-development can drastically modify behaviors and functions of the animal and the ecosystem, both of which can be inherited by future generations. Thus, the ecological inheritance from one generation to the next encompasses an inheritance of affordances. Geo-physical (including built environments) and social processes can alter the affordances in an individual's eco-niche. In this way, niche construction can alter the developmental trajectory of a collective system in small or extensive ways, which could be significant (in positive and negative ways) for group health and wellbeing. Conceptually, a form of life that focuses on the realization of affordances, without considering the effect of these affordances on health and wellbeing, might conceivably construct an environment where broader health and wellbeing affordances are depleted. Ecological dynamics predicts that a landscape of nature affordances, lived by a population as their form of life, contributes to increased health and wellbeing, given the embedded and embodied experiences provided by activities in the natural environment according to each individual's characteristics (Araújo et al., 2019a).

IMPLICATIONS FROM THE ECOLOGICAL DYNAMICS APPROACH FOR UNDERSTANDING AND ENHANCING HUMAN HEALTH AND WELLBEING

The first implication of the Ecological Dynamics approach is the realization that person-environment systems are interdependent. That is, the health outcomes experienced by an individual stem from the relationship between individual skills and characteristics (history, culture, emotions, physiology) and functional environmental characteristics or affordances. From this first animal-environment interdependence implication flows that health and wellbeing interventions and environments need to be designed to provide a wide range of health and wellbeing behavior enrichment affordances (Davids et al., 2016).

The second key implication is that affordances, available through the interaction between humans and natural environments, are richer and more conducive to health and wellbeing outcomes for the human being than heavily manicured urban environments. Practical connotations from this point suggest, for example, that urban design needs to appreciate and provide for key nature affordances, beyond playing fields and picnic areas, that invite a broader range of health and wellbeing behaviors (van Heezik and Brymer, 2018). From a research perspective priority should be placed on determining key affordances in natural contexts. For instance, recent falls prevention research in community dwelling older adults shows that improved gait adaptability is related to a decreased risk of sustaining a gait related fall (van Andel et al., 2018, 2019). This suggests that the design of gait-related activities in environments that include affordances that provoke gait-adaptability, such as those that are available in the natural environment, are needed to provoke adaptable gait and thereby prevent falls in older adults. Ironically, many of the environments constructed for older adults have been designed to take away such affordances. Think of the clinical, low risk environments in traditional nursing homes.

A third implication is that an organism actively molds the environment to better realize certain affordances appropriate for a particular animal, in this case the human animal. However, a potential ramification is that some affordances can be destroyed. Designing environments that maximize affordances for safety, disease minimization, and so on might also destroy affordances for flourishing (health) and empowering experiences (wellbeing). It is therefore important to consider how the construction of human environments maximize affordance potentials for human behaviors, especially health and wellbeing.

In summary, we presented an ecological framework that emphasizes the person-environment relationship as the appropriate scale for analysis and conceptualized it as explanatory for health benefits of human-nature relationships. Three relevant concepts were discussed: form of life, affordances and niche construction, as helpful for appreciating how acting in natural environments might benefit human health and wellbeing. The implications of this approach, from a health and wellbeing perspective, suggest that policy makers and urban designers need to work toward environmental designs that support a landscape of health and wellbeing affordances, that make use of the richness of natural environments.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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