NATURE AND ENVIRONMENT: THE PSYCHOLOGY OF ITS BENEFITS AND ITS PROTECTION

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NATURE AND ENVIRONMENT: THE PSYCHOLOGY OF ITS BENEFITS AND ITS PROTECTION

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Our Research Topic section entitled: "Nature and the environment: The psychology of its benefits and its protection" will have two main lines. The first line of articles will center upon cutting-edge research showing how interacting with nature, can affect health, well-being, and overall improve cognition and affect. Articles in this line will stress in what ways nature can improve psychological functioning and health and also discuss the theories and evidence as to why nature can improve psychological functioning. For this line, we welcome submission of articles that discuss the psychological, health and well-being benefits from interacting with nature as well as submissions that focus on theoretical considerations and underlying mechanisms that lead to the restorative effects of interacting with nature. Given that nature can have a positive impact on psychological functioning and overall health, it is also important to understand the variables that facilitate people's recognition of environmental issues that can help foster a more positive attitude towards the preservation of nature. This brings us to the second line of articles which will center upon the psychological mechanisms that make individuals more or less likely to accept the seriousness of environmental challenges such as climate change. Given the new cutting-edge research in this field we may be able to make individuals more proactive in the protection of the environment and more accepting of policy measures required to mitigate climate change. We see this research topic as a way for psychological scientists to contribute substantially to an important area of public debate and policy. For this line we welcome articles that will focus on ways in which people respond to various framings of policy relevant information and how morality may play into the individuals policy views that center on climate change and environmental protection.

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EDITORIAL
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Editorial: Nature and the Environment: The Psychology of Its Benefits and Its Protection

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Keywords: nature, climate change, benefits of natural environments, urban design, attention restoration theory

The goal of this Research Topic was to bring together research and scholarship from two seemingly disparate fields: (1) the psychological and health benefits attained by interacting with natural environments and (2) the variables that facilitate people's recognition of environmental issues that would foster a more positive attitude toward the protection of nature.

The first portion of this e-book concerns the positive benefits (health, psychological, affective, etc...) that can be gained from interacting with more natural environments. There is now a considerable amount of evidence in support of the beneficial effects that nature can have on an individual's cognitive functioning and health. Kuo (2015) provides an excellent review toward understanding he interaction of nature and health. Kuo hypothesizes a central pathway for how nature improves health through enhanced immune functioning. Furthermore, Kuo suggests public policy to implement green spaces with plants, soil, and moving water in areas where health risks are high as an inexpensive public health intervention.

Szolosi et al. (2014) examined if nature's perceived mysteriousness had an effect on direct cognitive benefits. They showed that with enough exposure to an image, more mysterious nature images achieved greater improvements in recognition performance than nature images with low perceived mystery (Szolosi et al., 2014). Capaldi et al. (2014) performed a meta-analysis regarding the potential beneficial relationship between nature and health. Reported vitality, positive affect, and life satisfaction all had a strong relationship with nature connectedness. This analysis further concluded strong associations between happiness and inclusion of nature in the self, nature relatedness, and connectedness to nature (Capaldi et al., 2014). Interestingly, participants do not necessarily have to be consciously aware of the restorative environmental stimuli to obtain the benefits. According to the results of Lin et al. (2014), participants received an effect of attention restoration with minimal or absent awareness to the restorative stimuli using digital images. We must also be cautious when it comes to some of this environmental research. Pearson and Craig (2014) performed a review of the existing literature and call for future research to focus on substantiating the rather simplistic dichotomy of "nature" vs. "built" environments (Pearson and Craig, 2014). The review by Pearson and Craig also brought up the topic of immersive of the nature intervention. Many studies have focused primarily on studying human interactions with only images of natural and urban environments. The authors suggest that future studies should explore different modes of immersion (e.g., virtual realities, enhanced means of exposure) when studying environmental impacts on psychological and physical health.

In addition to this expanding upon this simplistic dichotomy, it may also be important to examine differences in culture and urbanization (level of immersion in urban environments). Linnell et al. (2014), compared concentration abilities in two different cultures that reside in

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environments that have vastly different urbanization levels (Linnell et al., 2014). They found that urbanization can lead to a reduced ability to concentrate, as measured with a line bisection task, compared to individuals who reside in a less urbanized society.

In addition to documenting the differential benefits of nature, it is also important to try to understand what is it about nature itself that leads to these benefits. As previously stated, researchers have found beneficial effects simply from viewing pictures of nature. This suggests that there may be low-level visual features within natural environments that may lead to psychological benefits. Kardan et al. (2015) found that color-related and edge-related characteristics of nature interactively contribute to preferring one scene to another (Kardan et al., 2015). Spatial structure and color properties were quantified; then, nature and man-made environments were decomposed after being rated on subjective preference and naturalness. Multiple regression analysis showed that some of these features could significantly predict preference of images: straight-edge density, lower hue level, and higher diversity in saturation. A separate study, integrates design aesthetics, mathematics, and recent psychology theories (Hunter and Askarinejad, 2015). From this integration of methodologies, the authors developed a list of physical attributes that explained image features within the environment (e.g., horizon line, building distribution, natural phenomena). These attributes provide even more insight into objective environmental features that may explain why cognitive restoration occurs in natural environments. Furthermore, this research may aid in the design of urban areas to optimize the restorativeness of the built environment.

The second portion of this e-book centers on cutting-edge research for how to educate the general public on environmental issues, as well as public policy implementation. Jacquet et al. (2014) investigated motivational bases of environmental attitudes and behaviors by focusing on specific ideological factors, in addition to general psychological principles. The authors devise a dichotomy of mutually reinforcing influences: top-down (e.g., corporate strategy, mass media, and political discourse) and bottom-up (e.g., ego, group, and system justification). These influences converge at an ideological divide over climate change. The authors conclude that regardless of the influence, future messages must allocate more attention to how they are framed and delivered to the public. Another dichotomy exists between two moral attitudes, both pertaining to concerns for the environment: anthropocentric and biocentric (Rottman, 2014). Anthropocentric, a word which its prefix means "human" refers to the concerns aimed at preserving the welfare solely for humans. It is within the moral attitudes of biocentrism that a crucial environmental distinction should be made between harm and purity, particularly because it extends mental states and rights to non-human entities unlike anthropocentric attitudes. The study of these distinctions could provide moral clarity to issues such as greenhouse gas emissions and an end to deforestation. There is an even more pressing need to make individuals more proactive in protecting and conserving the environment. De Young (2014) posits that biophysical restraints, such as dwindling natural resources are not problems that can be solved; rather, they are complex predicaments that must be endured. The author praises the small experiment framework for its pragmatic exploration into useful environmental-person interactions, and calls for a development school of biophysical psychology to investigate ways to make individuals more accepting of policy measures to mitigate climate change. A concurrent review by Page and Page (2014) used a novel framework to create alternative perspectives on variables impacting pro-environmental activity and behavioral change. These variables can be later compared with other psychological variables derived from alternative theories of behavior. This research topic recognizes the eclectic contributions from mathematics, psychology, and public policy to encourage: proactive behaviors to preserve the environment; and research to continue investigating how and why interacting with natural environments are beneficial to both physical and psychological health.

AUTHOR CONTRIBUTIONS

DH and MB wrote the paper.

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MINI REVIEW
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How might contact with nature promote human health? Promising mechanisms and a possible central pathway

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How might contact with nature promote human health? Myriad studies have linked the two; at this time the task of identifying the mechanisms underlying this link is paramount. This article offers: (1) a compilation of plausible pathways between nature and health; (2) criteria for identifying a possible central pathway; and (3) one promising candidate for a central pathway. The 21 pathways identified here include environmental factors, physiological and psychological states, and behaviors or conditions, each of which has been empirically tied to nature and has implications for specific physical and mental health outcomes. While each is likely to contribute to nature's impacts on health to some degree and under some circumstances, this paper explores the possibility of a central pathway by proposing criteria for identifying such a pathway and illustrating their use. A particular pathway is more likely to be central if it can account for the size of nature's impacts on health, account for nature's specific health outcomes, and subsume other pathways. By these criteria, *enhanced immune functioning* emerges as one promising candidate for a central pathway between nature and health. There may be others.

Keywords: natural environment, greenspace, immune, mechanism, mental health, literature review

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Introduction

Contact with nature has been tied to health in a plenitude of studies. Time spent in and around tree-lined streets, gardens, parks, and forested and agricultural lands is consistently linked to objective, long-term health outcomes. The less green a person's surroundings, the higher their risk of morbidity and mortality – even when controlling for socioeconomic status and other possible confounding variables. The range of specific health outcomes tied to nature is startling, including depression and anxiety disorder, diabetes mellitus, attention deficit/hyperactivity disorder (ADHD), various infectious diseases, cancer, healing from surgery, obesity, birth outcomes, cardiovascular disease, musculoskeletal complaints, migraines, respiratory disease, and others, reviewed below. Finally, neighborhood greenness has been consistently tied to life expectancy and all-cause mortality (see Table 3 in the Supplementary Materials).

These findings raise the possibility that such contact is a major health determinant, and that greening may constitute a powerful, inexpensive public health intervention. It is also possible, however, that the consistent correlations between greener surroundings and better health reflect self-selection – healthy people moving to or staying in greener surroundings. Examining the potential pathways by which nature might promote health seems paramount — both to assess the credibility of a cause-and-effect link and to suggest possible nature-based health interventions. Toward that end, this article offers: (1) a compilation of plausible pathways between nature and health; (2) criteria for identifying a possible central pathway; and (3) one promising candidate for a central pathway.

How Nature Might Promote Health: Plausible Pathways

How might contact with nature promote health? To date, reviews and studies addressing multiple possible mechanisms (Groenewegen et al., 2006, 2012; Sugiyama et al., 2008; de Vries et al., 2013; Hartig et al., 2014) have focused on four – air quality, physical activity, stress, and social integration. But the burgeoning literature on nature benefits has revealed an abundance of possible mechanisms: as **Figure 1** shows, this review identifies 21 plausible causal pathways from nature to health. Each has been empirically tied to contact with nature while accounting for other factors, and is empirically or theoretically tied to specific health outcomes (for details on the scope of this review, see Table 1 in the Supplementary Materials). The 21 pathways identified here include environmental factors, physiological and psychological states, and behaviors or conditions, and are summarized below (for more details on each of these pathways, see Table 2 in the Supplementary Materials).

Environmental Conditions

Some of the plausible pathways from contact with nature to improved health stem from specific environmental conditions. Natural environments contain chemical and biological agents with known health implications. Many plants give off phytoncides — antimicrobial volatile organic compounds — which reduce blood pressure, alter autonomic activity, and boost immune functioning, among other effects (Komori et al., 1995; Dayawansa et al., 2003; Li et al., 2006, 2009). The air in forested and mountainous areas, and near moving water, contains high concentrations of negative air ions (Li et al., 2010), which reduce depression (Terman et al., 1998; Goel et al., 2005), among other effects (Table 2 in the Supplementary Materials). These environments also contain mycobacterium vaccae, a microorganism that appears to boost immune functioning (see Lowry et al., 2007 for review). Similarly, environmental biodiversity has been proposed to play a key role in immune function via its effects on the microorganisms living on skin and in the gut, although the evidence for this is mixed (Table 2 in the Supplementary Materials).

The sights and sounds of nature also have important physiological impacts. Window views and images of nature reduce sympathetic nervous activity and increase parasympathetic activity (e.g., Gladwell et al., 2012; Brown et al., 2013), restore attention (e.g., Berto, 2005), and promote healing from surgery (Ulrich, 1984). Sounds of nature played over headphones increase parasympathetic activation (Alvarsson et al., 2010). These sympathetic and parasympathetic effects drive the immune system's behavior (for review, see Kenney and Ganta, 2014), with long-term health consequences.

In built environments, trees and landscaping may promote health not only by contributing positive factors like phytoncides but also by reducing negative factors. Air pollution is associated with myocardial inflammation and respiratory conditions (Villarreal-Calderon et al., 2012). High temperatures can cause heat exhaustion, heat-related aggression and violence, and respiratory distress due to heat-related smog formation (Anderson, 2001; Akbari, 2002; Tawatsupa et al., 2012). And violence affects physical and mental health (e.g., Groves et al., 1993). Vegetation filters pollutants from the air (although see Table 2 in the Supplementary Materials for details), dampens the urban heat island (e.g., Souch and Souch, 1993), and appears to reduce violence (Table 2 in the Supplementary Materials for review).

Physiological and Psychological States

Some of the plausible pathways between contact with nature and health involve short-term physiological and psychological effects, which, if experienced regularly, could plausibly account for long-term health effects.

Blood tests before and after walks in different environments reveal that levels of health-protective factors increase after forest but not urban walks. Didehydroepiandrosterone (DHEA) increases after a forest walk (Li et al., 2011); DHEA has cardio protective, anti-obesity, and anti-diabetic properties (Bjørnerem et al., 2004). Similarly, time in nature increases adiponectin (Li et al., 2011), which protects against atherosclerosis, among other things (Table 2 in the Supplementary Materials), and the immune system's anti-cancer (so-called "Natural Killer," or NK) cells and related factors (Table 2 in the Supplementary Materials). NK cells play important protective roles in cancer, viral infections, pregnancy, and other health outcomes (Orange and Ballas, 2006).

Further, walks in forested, but not urban areas, reduce the levels of health risk factors, specifically inflammatory cytokines (Mao et al., 2012), and elevated blood glucose (Ohtsuka et al., 1998). Inflammatory cytokines are released by the immune system in response to threat, and have been implicated in diabetes, cardiovascular disease, and depression (Table 2 in the Supplementary Materials). Chronically elevated blood glucose carries multiple health risks, including blindness, nerve damage, and kidney failure (Sheetz and King, 2002). The powerful effects of a walk in a forest on blood glucose are particularly striking (Table 2 in the Supplementary Materials for review).

Contact with nature has a host of other physiological effects related to relaxation or stress reduction (Table 2 in the Supplementary Materials). The experience of nature helps shift individuals toward a state of deep relaxation and parasympathetic activity, which improves sleep (El-Sheikh et al., 2013), boosts immune function in a number of ways (Kang et al., 2011), and counters the adverse effects of stress on energy metabolism, insulin secretion, and inflammatory pathways (Bhasin et al., 2013). Evidence suggests this pathway contributes substantially to

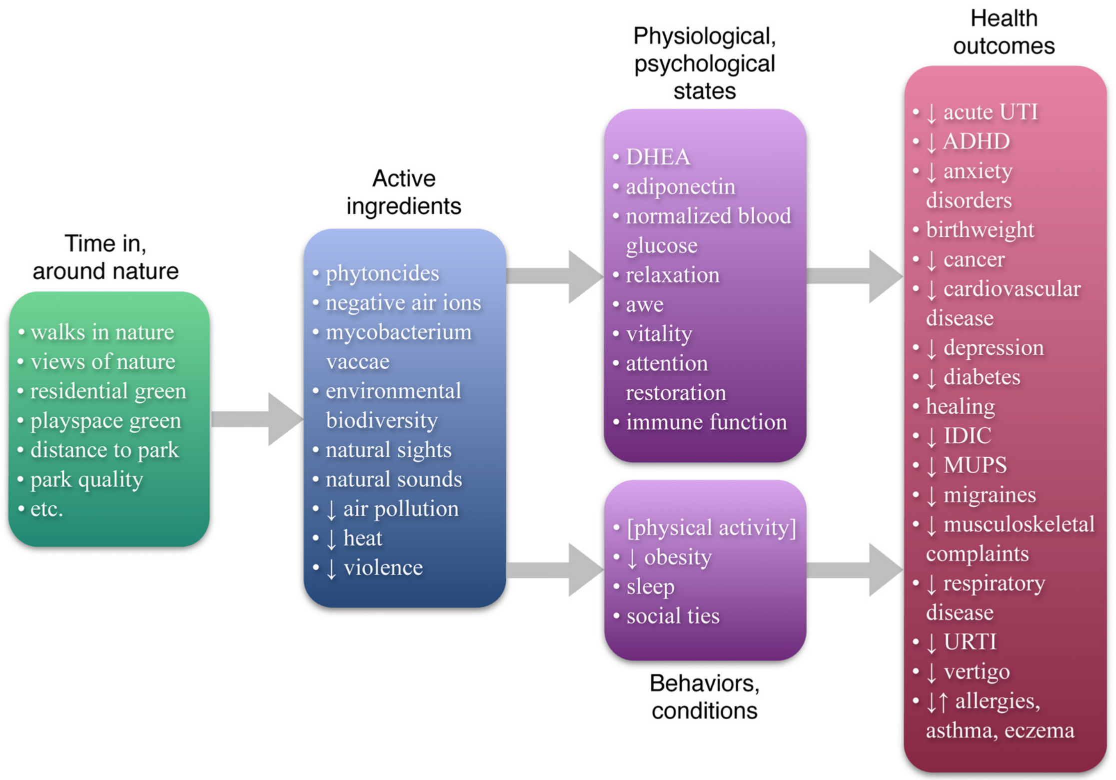

FIGURE 1 | The nature-health link: filling in the details. This Figure summarizes the state of the scientific literature on nature and health, listing (1) the "active ingredients" in nature that have been identified as having impacts on health or health antecedents; (2) physiological/psychological states, behaviors, and conditions tied to both nature and health; and (3) specific health outcomes that have been tied to nature (controlling for socioeconomic variables). Note that physical activity (in brackets) is only sometimes tied to nature; and that allergies, asthma, and eczema are sometimes positively and sometimes negatively tied to nature. DHEA: didehydroepiandrosterone; acute UTI: acute urinary tract infection; ADHD: attention deficit hyperactivity disorder; IDIC: infectious disease of the intestinal canal; MUPS: medically unexplained physical symptoms; URTI: upper respiratory tract infection.

the link between nature and health (Table 2 in the Supplementary Materials).

Three psychological effects of nature — experiences of awe (Shiota et al., 2007), enhanced vitality (Ryan et al., 2010), and attention restoration (Table 2 in the Supplementary Materials) — offer additional possible pathways between nature and health. Regular experiences of awe are tied to healthier, lower levels of inflammatory cytokines (Stellar et al., 2015); the ties between nature and awe, and awe and cytokines, respectively, may help explain the effects of forest walks on cytokines above. Similarly, feelings of vitality predict resistance to infection (Cohen et al., 2006) and lowered risk of mortality (Penninx et al., 2000). Attention restoration could theoretically reduce accidents caused by mental fatigue and, by bolstering impulse control, reduce risky health behaviors such as smoking, overeating, and drug or alcohol abuse (Wagner and Heatherton, 2010).

Behaviors and Conditions

The remaining four possible pathways between contact with nature and health identified here involve behaviors and conditions: physical activity, obesity, sleep, and social ties. Physical activity is a major contributor to health (Centers for Disease Control and Prevention [CDC], 2015), and intuitively we associate green space with physical activity — but empirically this relationship is surprisingly inconsistent (Table 2 in the Supplementary Materials) and may hold only under certain conditions and for certain populations. Perhaps still more surprising, while greener residential areas do not consistently predict physical activity, they do consistently predict lower rates of obesity (for review, see Table 2 in the Supplementary Materials); this suggests the pathway between nature and obesity may depend less on nature's effects on physical activity and more on its effects on adiponectin, stress, and impulse control. Both sleep and social ties are major contributors to health (Table 2 in the Supplementary Materials); contact with nature contributes to both better sleep (Morita et al., 2011; Astell-Burt et al., 2013) and stronger social ties (see Table 2 in the Supplementary Materials for review).

Exploring the Possibility of a Central Pathway

Each of the mechanisms above is likely to contribute to nature's impacts on health to some degree and under some circumstances.

Most likely, some pathways will play a larger role than others. This paper explores the possibility that one or a few pathways may explain the lion's share of the link between nature and health by proposing criteria for identifying central pathways and illustrating the application of these criteria.

First, a pathway is more likely to be central if it can account for the size of nature's impacts on health. A study of over 345,000 people living in greener and less green residential surroundings revealed large differences in the prevalence of disease; even after controlling for socioeconomic status, prevalence for 11 major categories of disease was at least 20% higher among the individuals living in less green surroundings (Maas et al., 2009). For a single pathway to plausibly account for the bulk of the tie between nature and health, the mechanism involved would need to have substantial effects on health, and be substantially affected by contact with nature.

Second, a pathway is more likely to be central if it can account for specific health outcomes tied to nature. Although health is often treated as a unitary construct in the nature-health literature, poor health takes a multiplicity of separable, largely independent forms. A pathway that leads to one health outcome may not lead to others; for example, reduced air pollution may lessen respiratory symptoms, but is not likely to affect ADHD symptoms. A central pathway between nature and health should account for many, if not most, of the specific health outcomes tied to nature.

Third, a pathway is more likely to be central if it subsumes other pathways. To the extent that multiple nature-health pathways feed into a particular pathway between nature and health, that pathway is more central to the relationship between nature and health.

These three criteria can be applied to any given pathway to determine its centrality. In this paper, they are applied to one particular pathway: enhanced immune functioning.

Criterion #1: Accounting for the Size of the Nature-Health Link

Determining whether a particular pathway can account for the size of the nature–health link requires examining the effect sizes for the nature–mechanism and mechanism–health relationships. For the immune system, the existing literature reveals both these effect sizes to be large.

Time spent in nature has substantial beneficial effects on the immune system, raising positive indicators, and lowering negative ones. Two 2-h forest walks on consecutive days increased the number and activity of anti-cancer NK cells by 50 and 56%, respectively, and activity remained significantly boosted even a month after returning to urban life — 23% higher than before the walks (Li, 2010). Moreover, extended time in a forest decreased inflammatory cytokines implicated in chronic disease by roughly one-half (Mao et al., 2012). Urban walks have no such effect.

The immune system, in turn, has powerful effects on health. The cytotoxic activity of NK cells is important in preventing cancer – in an 11-year study, the incidence of cancer among the individuals in the middle and top third of cytotoxic activity was roughly 40% less than that among individuals with low levels of NK activity (Imai et al., 2000). NK cells also play important health-promoting roles in fighting viral and other infections, in autoimmune disorders, and in pregnancy (see Orange and Ballas, 2006 for review). Moreover, inflammatory cytokines are thought to play an important role in a host of chronic diseases, including diabetes, cardiovascular disease, and depression (Cesari et al., 2003; Wellen and Hotamisligil, 2005; Dowlati et al., 2010).

It appears that enhanced immune function fulfills the first criterion for a central pathway: it can account for the size of nature's apparent impacts on health.

Criterion #2: Accounting for the Specific Health Outcomes Tied to Nature

Each specific health outcome tied to nature constitutes a testable hypothesis for any proposed central pathway; the more specific health outcomes a pathway can account for, the more central its role.

Contact with nature has been linked to a plethora of specific health outcomes; in general, the more contact with nature, the better the health outcome, even after controlling for socioeconomic status and other factors. For each of the following, available evidence points to a favorable impact: acute urinary tract infections, anxiety disorder, ADHD, birth outcomes, cancer, cardiovascular disease, depression, diabetes mellitus, healing from surgery, infectious disease of the intestinal canal, musculoskeletal complaints, medically unexplained physical symptoms (MUPS), migraines, upper respiratory tract infections, respiratory disease, and vertigo (for details, see Table 3 in the Supplemental Materials). For allergies, asthma, and eczema, the apparent impact of nature varies; depending on the specific measures used and the place, the relationships are positive, negative, or null (Table 3 in the Supplemental Materials).

To determine whether enhanced immune functioning could account for these specific health outcomes, the literature on immune functioning and each of the 18 specific outcomes was collected and reviewed. Available evidence indicates that enhanced immune functioning may be able to account, wholly or partially, for all 18 (see **Figure 2**).

One of the chief functions of the immune system is to ward off infectious disease, protecting the body from bacterial, parasitic, fungal, and viral infections (National Institutes of Health [NIH], 2012). Thus enhanced immune function could clearly explain why contact with nature is tied to lower rates of acute urinary tract infections, infectious disease of the intestinal canal, and upper respiratory tract infections. Further, for health outcomes with multiple possible origins, enhanced immune function can account for cases with infectious origins — for example, infectious forms of respiratory disease but perhaps not forms of respiratory disease with non-infectious origins. Similarly, enhanced immune function can account for MUPS and vertigo with infectious origins (Bovo et al., 2006; Deary et al., 2007, respectively).

Two other key roles of the immune system are to assist in wound healing, and to seek out and destroy tumor cells. Thus enhanced immune function can account for the effect of a hospital view of nature on recovery from surgery (Ulrich, 1984), as well as the relationship between residential greenness and

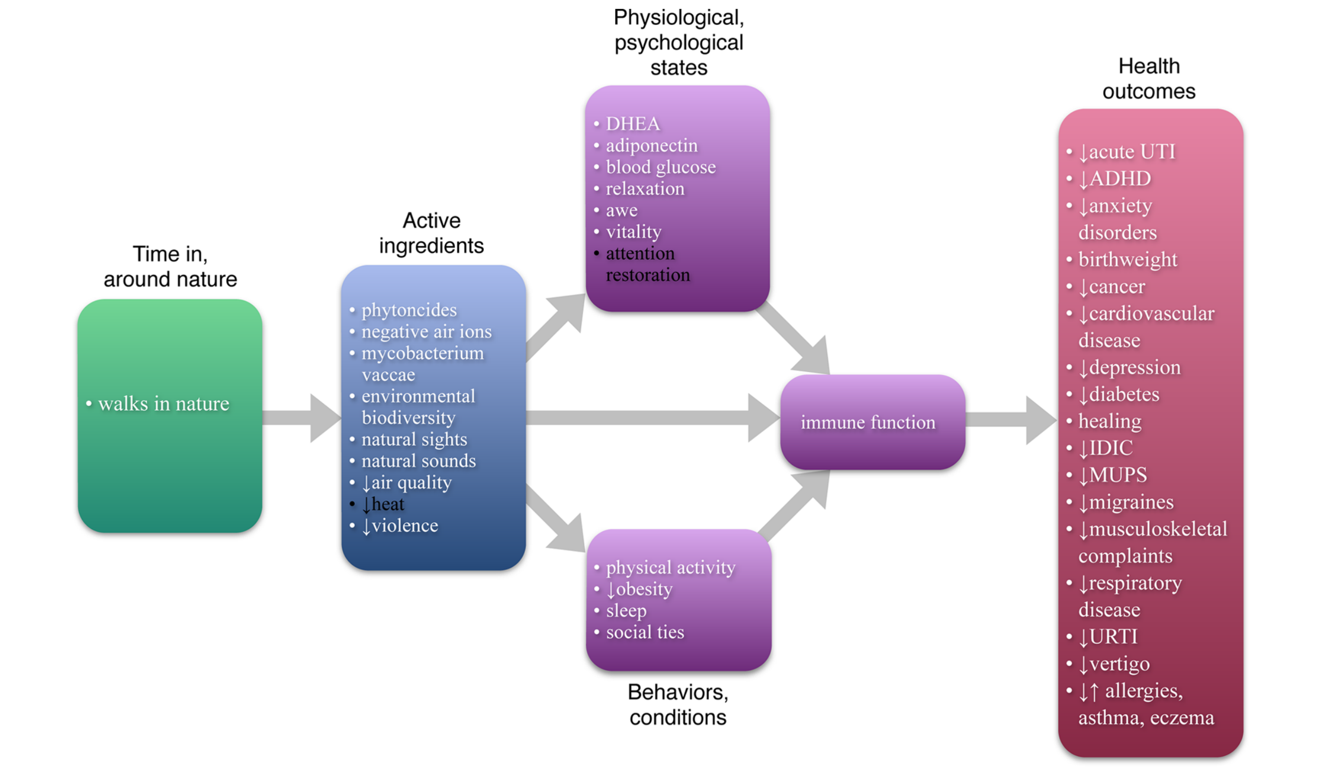

FIGURE 2 | Enhanced immune function as one possible central pathway. All items in white text are currently known or have been proposed to be causally tied to immune function. As the Figure shows, enhanced immune function can account, at least partially, for each of the specific health outcomes currently tied to nature and may subsume, at least partially, all but two of the other pathways. Other pathways may also contribute the nature-health link, and other central pathways may exist.

lower rates of cancer (Li et al., 2010). Further, the immune system governs inflammation, which is involved in allergies (National Institutes of Health [NIH], 2015), anxiety disorder (Salim et al., 2012), asthma (Murdoch and Lloyd, 2010), cardiovascular disease (Mari et al., 2002; Ho et al., 2010; Schiffrin, 2013), depression (Calabrese et al., 2014), diabetes mellitus (Pedicino et al., 2013), eczema (National Institutes of Health [NIH], 2014), and musculoskeletal complaints (Ji et al., 2002; Wang et al., 2011). Finally, immune functioning is important in healthy birth weight (Moffett et al., 2014), and is suspected to play a role in ADHD (Segman et al., 2002; Budziszewska et al., 2010) and migraines (Bruno et al., 2007).

Available evidence indicates that enhanced immune function fulfills the second criterion for a central pathway.

Criterion #3: Subsuming Other Pathways between Nature and Health

A nature–health pathway is more central if it subsumes other pathways; the more other pathways it subsumes, the more central its role. As **Figure 2** shows, the current literature suggests enhanced immune function can subsume as many as 18 out of the 20 other possible pathways between nature and health.

Enhanced immune function is known to wholly or partially subsume 11 other pathways. Each of the following is known to enhance immune function — adiponectin (Fantuzzi, 2013), reduced air pollution (e.g., Nadeau et al., 2010), awe (Stellar et al., 2015), normalized levels of blood glucose (as compared to elevated levels, Geerlings and Hoepelman, 1999), reduced obesity (de Heredia et al., 2012), physical activity (Shepherd et al., 1991), phytoncides (Li et al., 2009), better sleep (Besedovsky et al., 2012), social ties (Kiecolt-Glaser et al., 2002; Robles and Kiecolt-Glaser, 2003), relaxation and stress reduction (Abboud et al., 2012; Bhasin et al., 2013), and reduced immediate and long-term traumatic stress due to violence (e.g., Baum et al., 1993). Note that these pathways may be partially or wholly subsumed by the enhanced immune functioning pathway between nature and health; if a pathway contributes to health via both the immune system and other effects, it is partially subsumed by the immune function pathway.

For seven additional pathways, while there is no direct evidence tying them to human immune function, there is indirect evidence suggesting such a tie. DHEA (Hazeldine et al., 2010), mycobacterium vaccae (Lowry et al., 2007), and negative air ions (Yamada et al., 2006) are all known to improve immune function in mice. Vitality enhances resistance to upper respiratory tract infections (see vigor findings in Cohen et al., 2006), an effect mostly likely mediated via enhanced immune functioning. Both visual (e.g., Brown et al., 2013) and auditory (e.g., Alvarsson et al., 2010) nature stimuli are likely to boost immune function by way of their demonstrated effects on parasympathetic activity, and the subsequent effects of parasympathetic activity on immune function (Kenney and Ganta, 2014). And environmental biodiversity has been proposed to help train and regulate the immune system, although the findings here are correlational and mixed (e.g., Ruokolainen et al., 2014).

Enhanced immune function fulfills the third criterion for a central pathway.

Conclusion

This review reveals a multiplicity of mechanisms by which contact with nature might promote health, as well as a promising candidate for a central pathway. There may be other mechanisms, such as other physiological effects, reduced accidents, and healthier behaviors. There may also be other central contributors to the nature-health link – of those reviewed here, deep relaxation, attention restoration and impulse control, sleep, and social ties seem particularly worthy of attention. No doubt some of the plausible pathways identified here will prove either not to contribute substantially to nature's impact on health, or to contribute only under certain limited circumstances; here, the roles of improved air quality, environmental biodiversity and microbiota, and physical activity merit closer study.

These limitations notwithstanding, this review makes a number of contributions to our understanding of nature and health, to future investigation in this area, and to the creation of healthy human habitats. The multiplicity of nature–health pathways identified here lends credibility to the hypothesis that nature actually promotes health, as well as a potential explanation for the startling size and scope of nature's apparent impact. With so many contributing pathways operating in concert, the cumulative effect could be quite large even if many of the individual pathways contribute only a small effect – that is, the effect of exposure to phytoncides *plus* exposure to mycobacteria vaccae *plus* increased adiponectin *plus* stronger social ties *plus* better sleep, etc., could indeed be quite large, and if some of the pathways, such as enhanced immune function, contribute a large effect, the combined effect would be larger still.

For future work in this area, the criteria here give researchers interested in central mechanisms a means of using existing literature to assess the centrality of a particular mechanism. In addition the detailed reviews provided in the Supplementary Materials may provide a useful starting point for researchers interested in specific pathways or specific health outcomes of nature.

Finally, the findings here can help guide the creation of healthy human habitats. The existing literature speaks to the value not only of "wild" nature but also "everyday" nature – the views and green spaces where we live. That physical activity is not consistently related to greener environments suggests that our conceptualization of health-promoting greenspaces should center at least as much on oases as on ball fields, and on greenspaces for walking and quiet contemplation as much as on recreation areas. The findings here suggest that such oases should incorporate plants — especially trees, soil, and water (preferably moving) — and should be designed to induce feelings of deep relaxation, awe, and vitality. Providing these green oases, especially in areas where health risks are high and landscaping is sparse, might be an inexpensive, powerful public health intervention and address persisting health inequalities.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01093

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The benefits of mystery in nature on attention: assessing the impacts of presentation duration

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Although research has provided prodigious evidence in support of the cognitive benefits that natural settings have over urban settings, all nature is not equal. Within nature, natural settings that contain mystery are often among the most preferred nature scenes. With the prospect of acquiring new information, scenes of this type could more effectively elicit a person's sense of fascination, enabling that person to rest the more effortful forms of attention. The present study examined the direct cognitive benefits that mystery in nature has on attention. Settings of this sort presumably evoke a form of attention that is undemanding or effortless. In order to investigate that notion, participants ($n = 144$) completed a Recognition Memory Task (RMT) that evaluated recognition performance based on the presence of mystery and presentation duration (300 ms, 1 s, 5 s, and 10 s). Results revealed that with additional viewing time, images perceived high in mystery achieved greater improvements in recognition performance when compared to those images perceived low in mystery. Tests for mediation showed that the effect mystery had on recognition performance occurred through perceptions of fascination. Implications of these and other findings are discussed in the context of Attention Restoration Theory.

Keywords: mystery, fascination, attention restoration theory, recognition memory, mediation testing

INTRODUCTION

One of the many benefits often ascribed to interactions with nature is their ability to provide a person with rest and relief from the demands of everyday life (Kaplan and Kaplan, 1982; Knopf, 1987). A long walk in a nearby park, a view of a snow-capped mountain, or even the simple act of tending to the garden can be enough to alleviate the mental fatigue that may escalate throughout the course of a day. Research in this area has amassed a considerable amount of evidence in support of the beneficial effects that nature can have on a person's cognitive functioning (Hartig et al., 2003; Berto, 2005; Berman et al., 2008).

All nature however, is not equal. Certain types of natural settings are likely more supportive or effective at providing a person with the kind of rest needed to facilitate a state of mental recovery. Natural settings that contain patterns of mystery may be particularly effective at this aim, as previous research has shown mystery to be a strong predictor for environmental preference (Herzog and Kropscott, 2004; Stamps, 2004; Herzog, 2007). Consider a partially obstructed view, a view common to many nature or park settings. Scenes of this sort give the impression that there is more to gain by going deeper into the setting. The possibility of acquiring new information captures a person's interest, prompting that person to look more carefully through the leafy branches and slim tree trunks of a forest. The fact that the view is vaguely seen makes it all the more elusive, distant, and fascinating. Such sources of fascination presumably serve as a basis for resting attention (Cimprich, 1992; Kjellgren and Buhrkall, 2010).

Efforts to evaluate the effects that nature has on resting and restoring attention have often relied on approaches in which setting exposure occurs between a mental load task and a specific assessment of attention (Tennessen and Cimprich, 1995; Berto et al., 2010). Although approaches of this type can indicate the extent to which a particular setting can facilitate recovery, they do not necessarily implicate the cognitive processes that contribute to that recovery. In the present study, we adopted an alternative method in which setting exposure was part of the attention-related task. The intent of this approach and the current study was not to address restoration *per se*, but to examine the underlying mechanisms that presumably contribute to that outcome. The prevailing assumption is that settings that are cognitively restorative tend to engage forms of attention that are more effortless, allowing the more effortful mechanisms of attention an opportunity to rest (Kaplan, 1995). Attention Restoration Theory (ART) offers an explanation for why certain settings may facilitate the activation of these less demanding forms of attention (Kaplan, 1995).

ART, developed by the Kaplans (Kaplan and Kaplan, 1989), has served as the theoretical framework to help guide and explain why interactions with certain settings may lead to a restorative experience. As a concept, the restorative experience draws on the notion that after periods of prolonged use or under conditions of cognitive load, a person's capacity to direct attention can become fatigued (Hartig and Staats, 2006). Researchers have often referred to this condition as directed attention fatigue

(Kaplan, 2001; Felsten, 2009). Experiences of directed attention fatigue can be significant, interfering with a person's ability to function effectively in everyday life. As a cognitive capacity, directed attention allows a person to block out competing distractions in order to sustain focus during purposeful activity (Posner and Snyder, 1975; Kaplan and Berman, 2010). When the demands on this capacity become too overwhelming, people often seek out settings that offer some sense of respite or relief. For many people, interacting with nature fulfills that role.

According to ART, recovery from directed attention fatigue will occur to the extent that four factors are present in the person-environment interaction (Kaplan, 1995; Staats et al., 2003). To that end, for an experience to be restorative a person must garner a sense of physical and cognitive distance from the distractions and routines that place demand on his or her capacities (*being away*). Although gaining some degree of distance is important, restoration critically depends upon the presence of stimuli that are inherently interesting (*fascination*); a point examined further in the section that follows. Stimuli perceived as fascinating seemingly call forth a form of attention that is less demanding or effortless. By avoiding circumstances that require mental effort, a person can thereby rest the more effortful forms of attention (Berman et al., 2008; Kaplan, 1992, 1995). For that rest to be something other than fleeting though, a setting must also comprise a sense of scope and connectedness (*extent*). That is, the person-environment interaction must be rich and coherent enough to not only capture attention, but also sustain it.

The final restorative component addresses the need for a person's inclinations and purposes to be congruent with the requirements or demands imposed by a setting (*compatibility*). The degree to which a setting is compatible has a direct effect on human functioning (Herzog et al., 2011). Settings that do not support a person's intentions tend to require a considerable amount of mental effort. Although the restorative factors discussed here can exist in all types of settings, natural settings tend to hold all four at high levels (Herzog et al., 1997; Hartig et al., 2003). This is especially true for fascination, as nature is full of stimuli that tend to intrinsically capture a person's interest.

The term, fascination, draws on a distinction first proposed by James (1890). That distinction revolved around two mechanisms of attention: voluntary and involuntary. Voluntary attention is the willful act of directing mental effort so as to meet certain prescribed goals. In some situations, we may find that the stimulus patterns in an environment are essential to achieving a specific purpose, but yet fail to hold our interest. Voluntary or top-down processing allows a person to employ mental effort in order to ignore irrelevant information and focus solely on those items that are most salient. In contrast, involuntary attention (*fascination*) is largely a function of the interest or attraction that is present within an environment (Posner et al., 1980). On these occasions, the environmental patterns are so appealing that the activation or selection of attention occurs almost effortlessly. As a result, the processing of information is more bottom-up oriented.

According to Kaplan and Talbot (1983), human fascination tends to derive from certain cognitive contents and processes. The contents that frequently elicit fascination are often those objects that a person perceives as great value or great danger, or that hold evolutionary significance such as water, fire, or greenery (Kaplan, 1978). The processes that tend to engage attention more effortlessly are those that facilitate understanding or involvement (Kaplan and Kaplan, 1982). As people interact with a setting that offers both fascinating contents and processes, there are fewer demands placed on a person's processing capacity (Berto et al., 2008).

With the suggestion that there is more to see, natural settings that contain mystery can be very compelling. According to Kaplan and Kaplan (1982), the source of that fascination derives from strong biases early humans formed for visual information. As a species that did not rely on physical prowess for survival, humans tended to prefer environments that could facilitate understanding and involvement (Kaplan, 1987). Too much familiarity, and a person can become bored or tired. Too engaging, and a person could very easily experience feelings of anxiety or frustration. Settings that allow for a person to make sense while also promoting opportunities for exploration can not only engage, but also sustain a person's interest or fascination.

Mystery refers to those settings where a portion of the visual landscape is obstructed, enticing a person to go further (Hammitt, 1980; Kaplan and Kaplan, 1982). A bend in the trail, a view partially concealed by foliage, or a stream that meanders out of sight all possess attributes related to mystery (Gimblett et al., 1985). Scenes of this type often provide the prospect to acquire additional information. This in turn can engage a person's interest and enhance one's sense of involvement. Although there is ample evidence demonstrating the benefits nature has over urban environments (Tennessen and Cimprich, 1995; Herzog et al., 1997; Hartig and Staats, 2006), few studies have teased out the impact that specific scenic qualities within nature have on attention.

Previous studies have documented well the benefits that interactions with nature can have on a person's cognitive functioning (Kuo and Sullivan, 2001; Hartig et al., 2003; Berto, 2005; Berman et al., 2008; Taylor and Kuo, 2009). In many of those studies, the experimental design revolved around examining changes in performance for measures intended to evaluate attentional functioning. In the present research, we employed the use of a recognition memory task (RMT) in order to assess the mental workload that images perceived high or low in mystery had on a person's cognitive capacity. One of the major assumptions underlying ART is that recovery from directed attention fatigue is contingent upon resting that capacity (Kaplan, 1995).

In our use of the RMT, presentation duration served as an independent variable. In varying the amount of time a group of subjects had to study presented images, we not only were able to simulate demand on attention, but also address the extent to which certain images might evoke more automatic forms of processing. Faster presentation durations often correlate with mechanisms of attention that are more automatic in quality. With duration held as a constant for a person carrying out the RMT, performance on the RMT should vary as a function of the cognitive costs associated with a particular processing component (Barrouillet et al., 2004). For this study, the processing components were the images that appeared on the computer screen. Evaluations of task performance overall, as well as examining performance for both studied (hits) and non-studied (false alarm) images offered insight into the underlying mechanisms of attention activated during the RMT. That is, to what extent do scenes containing patterns of mystery engage or activate a type of attention that is more effortless in form? Further affirmation of these potential benefits occurred through our examination of the remember-know judgments made following recognition decisions.

In sum, we experimentally tested a series of hypotheses that aimed to understand the effects that high and low mystery nature images had on a person's attention. Initially, we expected to see differences in participants' recognition performance as a function of presentation duration and scene type (Hypothesis 1). We then anticipated that scene type would significantly predict recognition performance in that images perceived high in mystery would lead to greater rates of recognition performance (Hypothesis 2). In an attempt to explain this outcome, we first tested the supposition that scene type would predict levels of perceived fascination; images perceived high in mystery would result in higher levels of perceived fascination (Hypothesis 3). Finally, we expected that the effects of scene type on recognition performance would occur through perceptions of fascination (Hypothesis 4).

MATERIALS AND METHODS

PARTICIPANTS

A total of 229 introductory psychology students (51% female) received partial course credit for their participation in the study. Participant ages ranged from 18 to 54 ($M = 22$, $S.D. = 5.19$) with the greatest percentage of participants being in their freshman year of college (35.8%). Prior to participating in the study, all students were required to provide informed consent in accordance with the university's institutional review board.

RESEARCH DESIGN

Students involved in the study participated in one of three experimental phases. Initial efforts focused on establishing a set of images that best represented the extremes of trail scenes containing attributes commonly related to mystery (Gimblett et al., 1985). After obtaining such images, those images were then incorporated into the RMT. The third and final phase of the study involved an additional sample of participants assessing the same images integrated into the RMT for perceived fascination. Taken collectively, data obtained from each study phase provided a means by which to assess whether scores for fascination served as the generative mechanism through which mystery influenced the rate of recognition memory performance for images presented as part of the RMT.

STUDY PHASES

Mystery rating (phase 1)

Phase 1 of the study involved 38 students norming a set of nature trail scenes for the presence of mystery. Specific focus was devoted to obtaining images that reflected patterns perceived high in mystery and patterns perceived low in mystery (i.e., screening, distance of view, etc.). To accomplish that aim, participants viewed 160 images displayed on a computer screen one at a time. For each image presented, participants provided a response rating denoting the extent to which a setting promised more to be seen if they could have walked deeper into that setting ($0 =$ not at all, $6 =$ Very much so). The evaluation of the presented images was self-paced. The following scenic assessment for mystery demonstrated a high level of internal consistency with a Cronbach's alpha of 0.92.

Recognition memory task (phase 2)

Using a 2×4 experimental design, the RMT examined the effect that scene type (high vs. low mystery) and presentation duration (300 ms, 1 s, 5 s, and 10 s) had on participants' ($n = 144$) recognition memory performance. Presentation duration served as a between subjects variable, in which there were 36 participants in each duration. Scene type was manipulated within-subjects. Participants carried out the RMT in two parts: a study portion and a test portion. As an intentional learning task, participants were asked to study and memorize each image to the best of their ability. During the study portion of the task, participants viewed one of two subsets of 40 images, in which a computer screen randomly displayed each image for a specific duration. For a given duration, half of the participants viewed images from subset A at study, while the other half viewed images from subset B at study. This counter-balancing of images helped to ensure that participants' performance on the RMT was not merely an artifact of presenting certain images during the study portion of the task. Each subset comprised images from the two scene types examined; 20 images perceived to be low in mystery and 20 images perceived to be high in mystery. After the presentation of an image, a 100 pixel high by 100-pixel wide fixation point appeared for 200 ms.

During the test portion of the task, participants viewed the same 40 images randomly intermixed with the 40 new images (images from either Subset A or Subset B). Similar to the study portion of the RMT, the 40 new images included 20 images perceived to be low in mystery, and 20 images perceived to be high in mystery. For each image presented, participants had to decide whether or not an image was one they had previously seen (OLD) or an image that they were seeing for the first time (NEW). Participant responses yielded an accuracy score for each test image. OLD images correctly identified as OLD were grouped as hits. NEW images incorrectly identified as OLD were categorized as false alarms. In order to obtain a measure of recognition memory performance, participants' hit and false alarm rates for each scene type were calculated. Subtracting a participant's hit rate from his or her false alarm rate yielded a corrected recognition rate for each scene type. The rate of corrected recognition served as the dependent variable as it reflected a more accurate estimation of recognition performance.

In addition to assessing recognition memory performance, the RMT also provided a means by which to evaluate the strength of particular memory trace by asking participants to make remember-know judgments (Watson et al., 2003). If a participant responded that an image was "OLD" (meaning that it was presented during the study portion of the experiment), participants were then prompted to make a remember/know judgment for that image. A "REMEMBER" response indicated that there was something specific a participant remembered about the test image. A "KNOW" response indicated that a participant could not recollect any contextual details for a test image, but possessed a sense of familiarity that allowed that participant to be reasonably confident that the test image was presented during the study session.

Perceived fascination (phase 3)

A total of 47 students participated in Phase 3 of the study. Similar to norming a set of images for mystery, this phase focused on obtaining response ratings of perceived fascination for each of the 80 test images that appeared in the RMT. The study used a modified or shortened version of the fascination subscale originally designed as part of the Perceived Restorativeness Scale (Hartig et al., 1996). The scale used for this study consisted of three items that comprised: "This place has qualities that fascinate me," "I would like to spend more time looking at the surroundings here," and "My attention is drawn to many interesting things here." Items selected for inclusion as part of this study phase drew on factor analysis results presented in Hartig et al.'s (1996) earlier work. For each image presented on the computer screen, participants indicated to what extent the statements described the experience he or she was having while viewing a presented image (0 = Not at all, 6 = Very much so). Again, the evaluation of the presented images was self-paced. With a Cronbach's alpha of.96, the modified fascination subscale demonstrated a high level of internal consistency.

Measures of individual differences

In order to assess the success of randomly assigning participants to study phases, we included certain measures of individual difference as part of the study. Those measures included the Automated Operation Span Task (Aospan) and a slightly modified Dissociative Experience Scale (DES). A brief description of each measure follows.

Designed to assess working memory capacity, the Aospan is a computer based, mouse driven task that requires participants to solve a series of basic math operations that necessitate a "true" or "false" response. While completing this task, participants are also tasked with trying to remember the order of a set of unrelated letters. For the purpose of this study, we used participants' Aospan total score as an indicator of the attentional resources one had available to them when carrying out a cognitively challenging task (Unsworth et al., 2005). That score comprised the total number of correct letters in the correct position. With a.83 test-retest reliability coefficient, the Aospan is considered to be a highly reliable instrument.

The inclusion of the DES provided some additional insight into whether or not certain participants might have been predisposed toward involuntary shifts in attention (Bernstein and Putnam, 1986). As a self-report measure, the DES consists of 28 items that address feelings of derealization, depersonalization, as well as absorption. In the original measure, participants indicated their response to each item by placing a slash along a line numerically anchored. For the present study, participants denoted their response for each item in accordance to the provided semantic scale (Never, Rarely, Average, Frequently, Always). Each of the semantic ratings received a numerical value from 1 to 5. Using these values, we then calculated a mean DES score based on the sum average of participants responses to each of the items in the DES. In this study, the DES demonstrated strong reliability with a Cronbach's alpha of 0.89.

PROCEDURES

Each experimental phase ran in multiple lab sessions with 1 to 6 participants per session. Lab sessions lasted approximately 1½ h and involved participants completing a series of tasks. Following the review and completion of the study's consent document, each participant received a set of written instructions specific to the tasks dedicated to that study phase and lab session. To maintain a degree of uniformity, all participants who signed up for a given lab session participated in the same experimental phase. The experimenter facilitating the lab session read the instructions for the tasks aloud, making sure to provide ample opportunity to answer any possible questions. When all participants confirmed that they sufficiently understood the directions for the tasks that they were about to undertake, the experimenter guided participants to the start of the experiment, which took place via a computer.

Participants' initial involvement required them to complete a series of demographic questions presented on the computer screen. When participants had completed this portion of the experiment, they clicked on an icon labeled NEXT which then directed each participant to a screen that contained a brief instructional reminder for the upcoming task. After all participants indicated that they were ready to begin, they then clicked on the START icon displayed on the computer screen. The task that followed depended on the experimental phase that a participant was involved in during his or her lab session. The task of evaluating images for either mystery or fascination took between 20 and 30 min for participants to complete. Participants who carried out the RMT generally required 10–20 min for completion. Upon finishing one of these three opening tasks, the research team then provided participants with a short 2–3 min rest break.

Following the provided rest break, all participants regardless of their study phase, carried out the Aospan task. Completion of this task took participants between 15 and 20 min, after which the research team provided participants with another short 2–3 min rest break. With the conclusion of the second rest break, all participants completed the final two tasks of the lab session. The first was the DES, facilitated as a paper and pencil questionnaire. The second task was the English Fluency and Task questionnaire. Although not a cognitively based task, the questionnaire provided a means by which to review questionable or confounding data that might have resulted from language differences or from a participant having previous experience with the tasks used in the study. These final two tasks in the lab session took approximately 10 min or less to complete each. All lab sessions concluded with a short debriefing that aimed to provide participants with a more detailed explanation of the intentions for the study.

DATA ANALYSIS

In order to address each of the stated hypotheses, we conducted two primary sets of analyses. The first analysis involved conducting a Two-Way repeated-measures ANOVA in order to assess the effect that scene type (within-subjects factor) and presentation duration (between- subjects factor) had on a person's recognition memory performance. Results obtained from that analysis offered insight into whether images from a particular scene type evoked more automatic forms of processing. A comparison of participants' recognition performance for each scene type across all durations allowed us to better evaluate which durations to test for mediation; only those durations where participants' recognition performance was significantly different among scene types were tested.

Prior to testing for mediation it was necessary to first collapse the data garnered from the RMT down to a level that was consistent across each of the other two phases of the study. Although each phase of the study utilized a different group of participants, participants viewed the same images. As a result, testing for mediation at the image level was the most logical approach for data analysis. Examining data at the image level required calculating the mean recognition performance score for each of the 80 test images in the RMT (i.e., an items-analysis, collapsed across subject responses). To calculate that mean, data obtained from the RMT (Phase 2) was arranged in a manner that treated participants as variables and each image as a single observation[1].

Testing for mediation followed a three-step process that involved running a series of regression equations (Baron and Kenny, 1986; Kenny et al., 1998). **Figure 1** presents the mediation model used for this study. In the first step, recognition memory performance served as the criterion variable with scene type as the predictor (Path c). This regression analysis aimed to establish a total effect between scene type and the mean rate of recognition memory performance for each of the 80 test images. In the second step, scores for fascination served as the criterion variable with scene type as the predictor (Path a). In order for fascination to be a mediating variable, variation in scene type had to significantly account for variation in scores for fascination. In the third and final step, recognition memory performance served as the criterion variable with both scene type (Path c) and perceived fascination as predictors (Path b). The function of this final regression analysis was to estimate the effect of scene type on the mean rate of recognition memory performance for each image (Path c′), when controlling for scores of fascination. If fascination fully or partially mediated the relationship between scene type and recognition memory, then the link between scene type and recognition memory would disappear or diminish as part of this regression analysis.

RESULTS

MANIPULATION CHECK

Given that individual differences in attention could have played a role in participants' ability to carry out certain tasks in the study, we attempted to ensure that there were minimal between group differences, and that groups were as homogenous as possible. As shown in **Table 1**, participants' total Aospan scores were relatively comparable across each phase of the study and consistent with scores found in similar works (Unsworth et al., 2005). Results from a One-Way ANOVA confirmed these initial findings as no significant differences were found between participants' total Aospan scores based on study phase, $F_{(2,\ 229)} = 1.86$, $p = 0.157$. In reviewing participants' scores on the DES, participants seemed to respond to the items of this scale in a similar fashion across each

[1]Within a given duration, half of the participants ($n = 18$) viewed one subset of images (i.e., images 1–40; Subset A) at study while the other half viewed a different subset of images (i.e., images 41–80; Subset B) at study. Participants in "Subset A" provided the hit rate for images 1–40, and the false alarm rate for images 41–80. Participants in "Subset B" provided the hit rate for images 41–80, and the false alarm rate for images 1–40. To determine the mean hit rate or mean false alarm rate of a given image, one simply divided the total of number of hits or false alarms for a given image by the total number of participants within that specific subset. The resulting percentage represented the mean hit or false alarm rate for an image. Subtracting the mean hit rate of an image from the mean false alarm rate of the same image produced the mean rate of corrected recognition performance for that image.

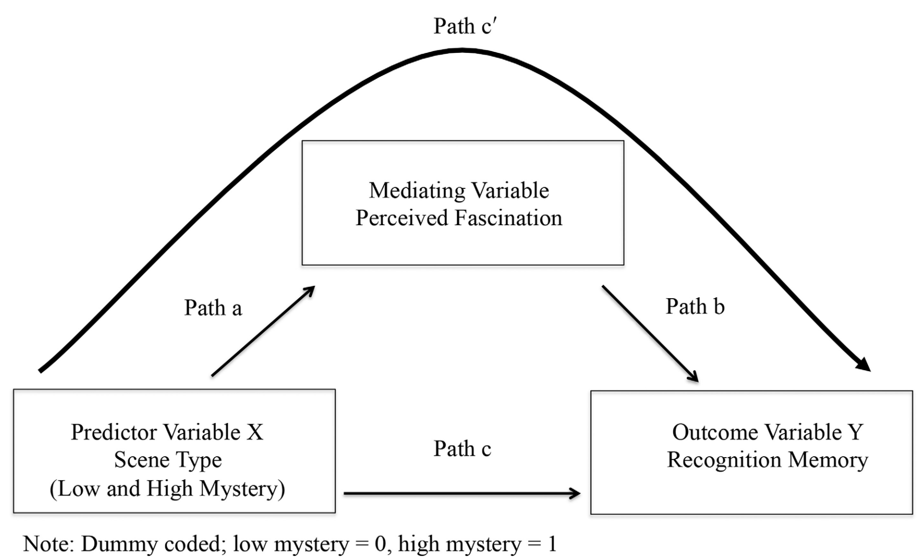

FIGURE 1 | Diagram of complete mediation model.

phase of the study (see **Table 1**). Results from a One-Way ANOVA again indicated that there were no significant differences between participants' average DES score, $F_{(2, 229)} = 1.78, p = 0.170$, based on study phase.

Table 1 | Distribution of Individual Differences.

	Mean	Std.	Skewness	Kurtosis
Phase 1 (*n* = 38)				
AOSPAN	59.82	9.57	−0.101	−0.847
DES	1.85	0.324	0.398	−0.780
Phase 2 (*n* = 144)				
300 ms (n = 36)				
AOSPAN	56.28	13.58	−0.950	0.092
DES	1.72	0.448	1.57	3.55
1 s (n = 36)				
AOSPAN	53.69	17.81	−1.40	1.39
DES	1.92	0.432	0.915	0.835
5 s (n = 36)				
AOSPAN	52.91	28.03	−0.952	0.898
DES	1.99	0.497	0.708	−0.099
10 s (n =36)				
AOSPAN	59.19	11.82	−1.56	3.25
DES	1.94	0.427	1.49	3.34
Phase 3 (*n* = 47)				
AOPSAN	52.98	13.40	−0.936	0.898
DES	1.76	0.368	1.06	2.70

MYSTERY RATING (PHASE 1)

Results from Phase 1 appeared in the form of point ratings for mystery for each image rated by a participant. The analysis of those results involved examining the arithmetic means and standard deviations for each image through rank order. Standard deviations served as a measure of consensus among participants. Data analysis resulted in the selection of 80 images, 40 of which represented the highest ranked images (high mystery; $M = 4.02$, $SD = 0.30$), and 40 of which represented the lowest ranked images (low mystery; $M = 2.51$, $SD = 0.165$)[2]. Overall, response ratings derived from Phase 1 ranged on average from 1.89 to 4.89. As an additional manipulation check, an independent *t*-test demonstrated that images selected and grouped as low mystery and high mystery were statistically different $t_{(78)} = 7.77$, $p < 0.05$ in terms of their provided mean response rating. Results garnered from the following scenic assessment seemed to suggest and support the notion that mystery was a perceivable attribute in the trail scenes used for the present study (see **Figure 2**).

RECOGNITION MEMORY TASK (PHASE 2)

Hit and false alarm rates for RMT

Although rates of corrected recognition served as the criterion of interest in testing most of the study's hypotheses, analyses of hit and false alarm rates for the RMT offered a unique perspective from which to understand the contributions each factor played in recognition performance. As shown in **Figure 3**, participants correctly identified low mystery images seen at study more often than high mystery images for all durations except the 10 s duration. When examining changes in hit rate across time, however, the percentage of increase in hit rate for low mystery images from 300 ms to 10 s was 25%, whereas the percentage of increase among high mystery images for the same durations was 65%.

A repeated measures ANOVA showed a significant main effect for scene type, $F_{(1, 140)} = 11.74$, $p < 0.01$, $\eta^2 = 0.08$. As well, that analysis indicated the presence of an interaction effect for scene type and presentation duration, $F_{(1, 140)} = 3.29$, $p < 0.05$, $\eta^2 = 0.07$. An examination of simple main effects showed that participants' hit rate varied significantly for the 300 ms duration, $F_{(1, 35)} = 8.84$, $p < 0.05$, $\eta^2 = 0.20$, and 1 s duration, $F_{(1, 35)} = 6.67$, $p < 0.05$, $\eta^2 = 0.16$. Significant differences in hit rate did not occur at the 5 s duration, $F_{(1, 35)} = 1.13$, $p = 0.295$, $\eta^2 = 0.03$, or 10 s duration, $F_{(1, 35)} = 0.381$, $p = 0.541$, $\eta^2 = 0.01$. In these later durations, it would appear that images perceived high in mystery benefited more from the additional time given to study images as part of the RMT.

A review of false alarm rates offered some additional insight into the effect that scene type and presentation duration had on recognition performance. The data obtained from the RMT demonstrated that while low mystery images garnered a rather high hit rate, the false alarm rate for these images was also rather high (see **Figure 3**). Thus, it would appear that participants exercised a fairly liberal response pattern for low mystery images regardless if they had seen those images at study or not. Among images perceived high in mystery, participants were far less apt to erroneously identify images seen at study as "NEW," especially when given more time to study those images. Similar response patterns often occur for low frequency words such as "silo" or "loft" (Otani and Whiteman, 1993). High mystery images, specifically high images never before seen, seemingly stood out, making it easier to discriminate between studied and non-studied images. This finding was reinforced as data denoted a significant main effect for scene type, $F_{(1, 140)} = 117.76$, $p < 0.001$, partial $\eta^2 = 0.45$.

Further review of false alarm data revealed that an interaction effect was not present, $F_{(1, 140)} = 1.46$, $p = 0.229$, partial $\eta^2 = 0.03$. A test of between subject effects indicated that false alarm rates varied significantly based on the duration of stimulus presentation, $F_{(3, 140)} = 3.94$, $p < 0.05$, $\eta^2 = 0.08$. That is, with additional study time, there was a general reduction in participants' false alarm rate, with the most notable reduction in false alarms emerging at the longest duration (10 s).

Hypothesis 1

A review of participants' corrected recognition performance scores across all durations (see **Figure 4**) illustrated that under the proxy of time, high mystery images achieved a greater level of performance in a shorter period of time when compared to low mystery images. The results of the Two-Way repeated measures ANOVA indicated a significant main effect for scene type, $F_{(1, 140)} = 41.27$, $p < 0.05$, $\eta^2 = 0.23$. As predicted (Hypothesis 1), that analysis also revealed a significant interaction effect for

[2]The complete RMT image set has been made available as a supplementary resource, as well normative data (i.e., means, standard deviations) for mystery and fascination ratings for corresponding images.

FIGURE 2 | Example of a high mystery (left) and low mystery (right) image.

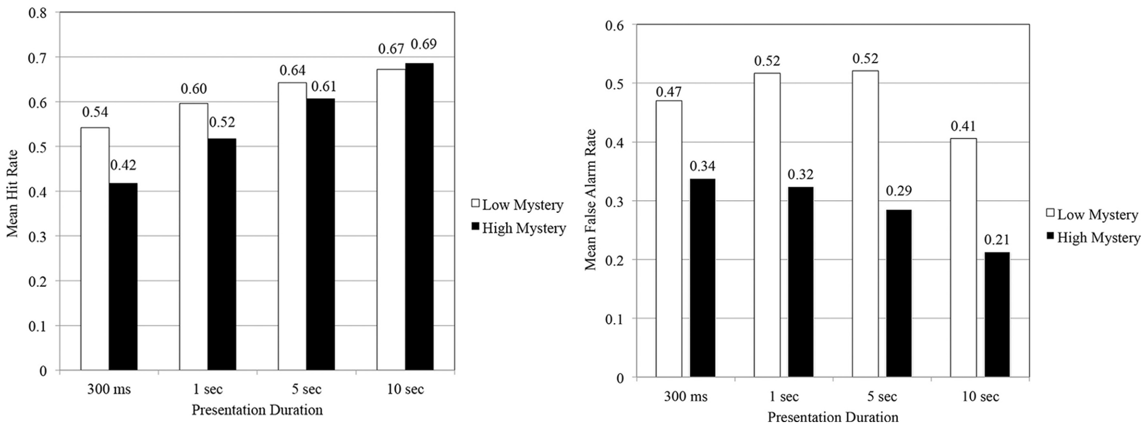

FIGURE 3 | Mean hit rates and false alarm rates as a function of scene type and presentation duration.

scene type and presentation duration, $F_{(3,\ 140)} = 4.99$, $p < 0.05$, $\eta^2 = 0.10$. In order to better understand the nature of that interaction, an examination of simple main effects followed. At the fastest of the four durations, 300 ms, participants' corrected recognition performance did not vary significantly based on scene type, $F_{(1,\ 35)} = 0.031$, $p = 0.861$, $\eta^2 = 0.001$. Study findings, however, did indicate that participants' corrected rate of recognition performance varied significantly based on scene type for the 1 s $F_{(1,\ 35)} = 6.12$, $p < 0.05$, $\eta^2 = 0.15$, 5 s $F_{(1,\ 35)} = 44.92$, $p < 0.001$, $\eta^2 = 0.56$, and 10 s $F_{(1,\ 35)} = 51.84$, $p < 0.001$, $\eta^2 = 0.60$, durations. Under these conditions, images perceived high in mystery conveyed the greatest benefit in terms of performance on the RMT. As a result, tests for mediation focused solely on these specific durations where statistical differences for scene type existed.

Response rates for remember-know judgments

An examination of Remember (R) and Know (K) response rates provided an additional measure from which to understand the effect that scene type and presentation duration had on participants' recognition memory (see **Table 2**). In reviewing the presented R and K response probabilities, one can better assess the composition of recognition decisions. That is, the sum of the response rates for R and K judgments equals the response rates for recognition hits or false alarms, respectively, for a given scene type and duration. In the present study, there are certain response patterns that are noteworthy.

Among high mystery images seen at study, the rate of R (0.204) and K (0.214) responses at the 300 ms duration were fairly comparable. As the amount of study time increased (10 s), however, participants were more likely to provide an R response (0.478), compared to a K response (0.213). Although a similar pattern appeared for low mystery images, the distinction between R and K responses was not as pronounced as it was for high mystery images. Results from a repeated measures ANOVA indicated a significant interaction effect among R responses for studied images based on scene type and presentation duration, $F_{(3,140)} = 4.38$, $p < 0.01$, $\eta^2 = 0.08$. Simple main effects revealed that there was no difference in R response rates at the 300 ms duration, $F_{(1,\ 35)} = 0.008$, $p = 0.928$, $\eta^2 = 0.00$, 1 s duration, $F_{(1,\ 35)} = 0.790$, $p = 0.380$, $\eta^2 = 0.02$, or 5 s duration, $F_{(1,\ 35)} = 0.079$, $p = 0.780$, $\eta^2 = 0.00$. At the 10 s duration, however, simple main effects indicated significant differences in recollection responses among studied images based on scene type, $F_{(1,\ 35)} = 20.98$, $p < 0.001$, $\eta^2 = 0.38$ Drawing on these results, it appears that with additional time to study an image, participants had a far easier time recollecting certain contextual details for images perceived high in mystery compared to images perceived low in mystery.

Similar to recognition decisions, a review of R and K false alarm rates provides a more complete picture from which to assess the pattern of responses made by participants. The rate of false alarms for R and K responses is consistent with earlier findings obtained in our evaluation of participants' recognition performance (see **Table 2**). That is, images perceived high in mystery seemed to offer participants certain discriminative benefits over low mystery images. In general, participants were less likely to inaccurately identify a high mystery image as one that they could recollect with some detail. Results obtained from conducting a repeated measures ANOVA supported this notion as a evidence indicated a significant main effect for scene type, $F_{(1,\ 140)} = 18.35$, $p < 0.001$, $\eta^2 = 0.12$. Results from this analysis did not, however, reveal the presence of an interaction effect, $F_{(3,\ 140)} = 1.28$, $p = 0.282$, $\eta^2 = 0.03$. When viewed in conjunction with K false alarms, there would seem to be evidence that speaks to the liberal response pattern found in participants' rates of recognition performance for low mystery images. At the longer durations, images perceived low in mystery still elicited higher rates of K responses (5 s = 0.307, 10 s = 0.286). Thus, participants appeared to have a harder time distinguishing between studied and non-studied low mystery images.

As a final appraisal, we examined the proportion of R-K responses after correcting for hits and false alarms (see **Figure 5**). Initial findings suggested that overall, images perceived high in mystery were more likely to elicit R responses from participants (0.41), compared to low mystery images (0.24).

Results obtained from a repeated measures ANOVA indicated a significant interaction effect, $F_{(3,\ 140)} = 5.50$, $p < 0.01$, $\eta^2 = 0.11$. Simple main effects showed no significant differences for the 300 ms duration, $F_{(1,\ 35)} = 0.167$, $p = 0.686$, $\eta^2 = 0.005$, and 1 s duration, $F_{(1,\ 35)} = 0.205$, $p = 0.654$, $\eta^2 = 0.006$. This was not the case at the two longer durations. Evidence obtained from the RMT indicated significant differences in participants' corrected rate of remember responses for the 5 s duration, $F_{(1,\ 35)} = 5.70$, $p < 0.05$, $\eta^2 = 0.14$ and 10 s duration, $F_{(1,\ 35)} = 34.93$, $p < 0.001$, $\eta^2 = 0.50$. With additional study time, participants were more likely to recollect the contextual details of high mystery images compared to those grouped as low mystery. The pattern of results obtained from the R-K procedure seems to follow the same trend found in participants' recognition performance.

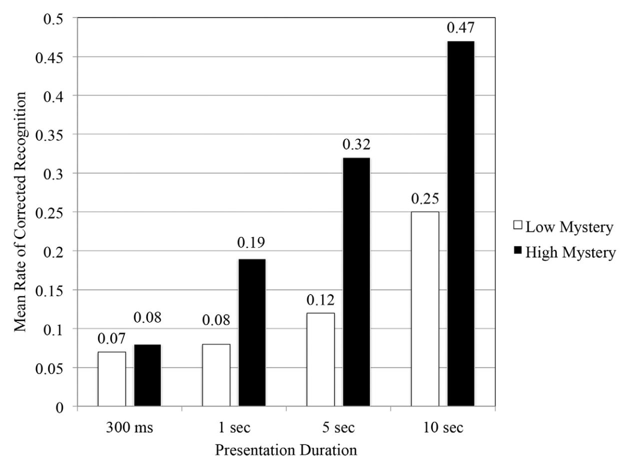

FIGURE 4 | Mean rate of corrected recognition as function of scene type and presentation duration.

Table 2 | Response probability as a function of presentation duration and scene type.

	Hits		False alarms	
	Low mystery	**High mystery**	**Low mystery**	**High mystery**
300 ms				
Remember	0.207	0.204	0.158	0.140
Know	0.335	0.214	0.311	0.189
1 s				
Remember	0.292	0.269	0.189	0.154
Know	0.304	0.249	0.328	0.168
5 s				
Remember	0.340	0.351	0.200	0.119
Know	0.310	0.258	0.307	0.165
10 s				
Remember	0.356	0.478	0.122	0.068
Know	0.338	0.213	0.286	0.149

PERCEIVED FASCINATION (PHASE 3)

Prior to running tests for mediation, mean fascination ratings were calculated for each RMT test image presented in Phase 3. Calculating mean fascination ratings involved taking the sum average of participants' responses to the three fascination items presented for each test image. Results from an independent *t*-test indicated that fascination ratings for low mystery ($M = 2.59$, $SD = 1.33$) and high mystery ($M = 3.11$, $SD = 1.24$) images were statistically different, $t_{(78)} = -6.708$, $p < 0.001$. Such findings support the proposed link between mystery and fascination

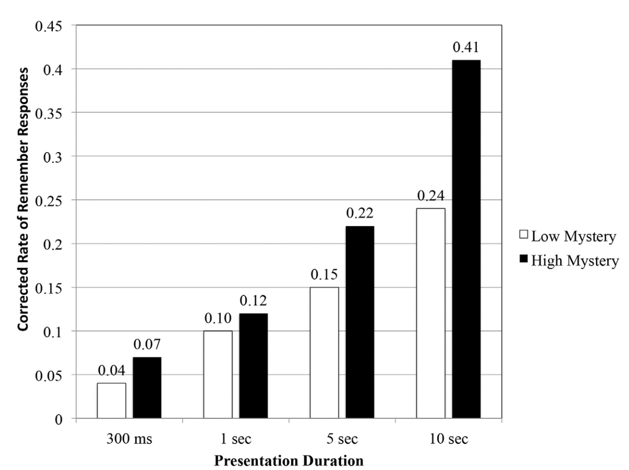

FIGURE 5 | Corrected rate of remember responses as a function of scene type and presentation duration.

found within the literature (Kaplan, 1978). With each of the variables in the mediation model represented, examining the indirect effects that fascination had on recognition performance via scene type could then proceed.

TESTING FOR MEDIATION

Tests for mediation provided an opportunity to assess if scores for fascination served as the generative mechanism through which scene type influenced recognition performance. In accordance to Kenny et al. (1998), mediation testing involved running a series of regression equations. These analyses focused on the relations between scene type and recognition performance (Hypothesis 2), scene type and perceived fascination (Hypothesis 3), as well as fascination's role in mediating the effect scene type had on recognition (Hypothesis 4). In order to carry out the required regression equations, we first calculated the mean hit rate, false alarm rate, and corrected recognition rate for each test image ($n = 80$). As a result, tests for mediation occurred as items-analysis of RMT performance. Results of the regression analyses follow below.

Hypothesis 2

Initial tests for mediation focused on the 1 s duration. Images presented at this duration were among the first to demonstrate differences in recognition performance based on the type of image viewed. Despite these differences, however, the effect of scene type on corrected recognition was not significant ($R = 0.219$, $p < 0.051$, $\beta = 0.219$, $t = 1.99$, $p = 0.051$). Without the presence of a total effect, further testing for mediation at this duration did not continue as outlined by Baron and Kenny (1986). Testing for mediation at the 5 and 10 s durations did, however, yield evidence that confirmed the presence of a total effect (Path c). Regression results indicated that scene type significantly predicted recognition performance scores at both the 5 s ($R = 0.445$, $p < 0.001$, $\beta = 0.445$, $t = 4.38$, $p < 0.001$) and 10 s durations ($R = 0.425$, $p < 0.001$, $\beta = 0.425$, $t = 4.15$, $p < 0.001$). As hypothesized, the direction of this relationship was positive in that images perceived high in mystery resulted in improved rates of recognition performance.

Hypothesis 3

Having met the first requirement for mediation as predicted, a second regression equation assessed the effect that scene type had on mean scores for fascination (Path a). If the cognitive effects of mystery in nature presumably evoke more bottom-up forms of processing, then images perceived high in mystery should yield elevated ratings for fascination. Consistent with the proposed hypothesis (H3), variations in scene type significantly accounted for variations in mean fascination scores ($R = 0.605$, $p < 0.001$, $\beta = 0.605$, $t = 6.71$, $p < 0.001$). That is, images perceived high in mystery tended to produce higher scores for fascination. Results obtained from this analysis fulfilled the second criterion for mediation; establishing a significant relationship between the predictor variable and the presumed mediating variable.

Hypothesis 4

In the third and final regression equation, scene type (Path c) and fascination (Path b) served as predictors to estimate the effect of scene type on corrected recognition when controlling for fascination (Path c′). If the cognitive benefits that mystery has on recognition performance occur via its effects on fascination, then the mystery-recognition relationship should statistically depend on the mystery-fascination relationship. With that in mind, if fascination is the sole mediating variable responsible for the effect that scene type has on recognition performance, then this effect should disappear when controlling for fascination. If fascination partially mediates the effect that scene type has on recognition, then the relationship between scene type and recognition should diminish but remain significant. Tests for mediation demonstrated that the relationship between scene type and corrected recognition when controlling for fascination was no longer significant at both the 5 s ($R = 0.631$, $p < 0.001$, $\beta = 0.105$, $t = 0.942$, $p = 0.349$) and 10 s durations ($R = 0.531$, $p < 0.001$, $\beta = 0.184$, $t = 1.52$, $p = 0.134$). This in turn suggests that the effect of scene type on recognition performance was almost fully mediated by differences in perceived fascination for natural scenes presented in the RMT. With significant reductions in Beta, tests for mediation demonstrated, as predicted, that fascination was indeed a potent mediating variable.

DISCUSSION

In the present study, we set out to examine the cognitive benefits that mystery in nature had on attention. Findings from the study revealed several interesting insights. First, recognition performance among images perceived high in mystery increased disproportionately more over time than images perceived low in mystery. That is, at the fastest duration (300 ms), recognition performance among high mystery and low mystery images was no different. With additional study time however, recognition performance increased for both scene types, but significantly more so for images of the high mystery variety. The evidence garnered here not only provides a more focused appraisal of the cognitive processes activated when viewing nature scenes containing mystery, but also hints at the restorative potential that these kinds of settings may possess.

Our second major finding centers on results we obtained in testing for mediation. Initial tests indicated that mystery served as a powerful predictor in recognition performance. In a separate but related test, the data also demonstrated that mystery served as an effective predictor for perceptions of fascination. That is, images perceived high in mystery tended to yield higher ratings of perceived fascination for nature scenes used in the test portion of the RMT. Having met these initial conditions, our final analysis confirmed that the effects of mystery on attention occurred almost fully through perceptions of fascination.

In the information that follows, we consider the implications that these findings may have on our understanding of the cognitive benefits derived from interacting with nature. Our initial discussion focuses on the results obtained from the RMT as rates of recognition performance hint at the activation of certain forms of cognitive processing. We then address the repercussions that this might have in our interpretation of fascination, a factor believed to have a central role in the restorative process.

The study proceeded with the expectation that images perceived high in mystery would offer certain benefits over low mystery images in terms of recognition. The underlying contention was that with the prospect of acquiring additional information, settings perceived high in mystery would likely be more apt to engage a person's interest, and thus better positioned to evoke a more effortless form of attention (Kaplan, 1978). A review of recognition performance rates at the 300 ms duration provided the best prospect to test this supposition. At that presentation rate, processing often reflects a more automatic or effortless response, and should function effectively in a high workload situation (Schneider and Chein, 2003). As previously stated, there was no difference in recognition performance between the two scene types at the fastest presentation duration. As well, rates of recognition performance at this duration were rather low. This would seem to suggest that the processing of images was more top-down oriented, and thus required some expenditure of effort.

From a theoretical perspective, ART may provide some explanation for this outcome. Although sources of interest or fascination play a critical role in the restorative process, they are not sufficient by themselves. ART posits that fascination is just one of four interrelated factors that is necessary for a person to achieve the rest required for attentional recovery (Hartig et al., 1997; Kaplan and Berman, 2010). Within the context of the RMT, experiencing a sense of being away, extent, or compatibility might have been particularly challenging, especially at the fastest duration. Images presented at 300 ms likely did not allow a person enough time to establish the cognitive distance needed to free oneself from the demands occupying the mind. Instead of allowing fascination to come into function, the demands of the task maintained their prominence as images presented at study appeared at a rapid rate in succession.

In order to reduce the demands on one's cognitive capacity, ART also suggests that experiences of fascination must reflect a more persistent quality (Kaplan, 1995). Opportunities for sustained fascination occur when a person interacts with a setting that provides some sense of extent (Kaplan, 2001). Settings of this sort tend to be comprised of features that are not only rich in their content, but possess some degree of coherence. Collectively, these qualities help to establish the sensation that a person is experiencing a "whole other world" (Kaplan, 1995, p. 173). With so much to see, natural settings that possess ample content and structure tend to allow a person to remain engaged (Kaplan and Kaplan, 1989). In presenting images at the fastest duration, there was likely not enough time for a person to readily organize or explore the elements of the immediately perceived image. Given that consideration, one might presume that there was little opportunity to capture fascination, let alone sustain it over time.

The most discernible explanation for the results obtained in the fastest duration could be that the RMT lacked a degree of compatibility. Settings that do not support a person's intentions tend to require a considerable amount of mental effort (Herzog et al., 2011). With the presentation of images occurring at a fast rate, the demands imposed by the environment (task) were likely too great for the intention of encoding images into memory. Realistically, however, there are few scenarios where a person's interaction with a natural setting is for a mere fraction of a second. More often than not, a person has ample time to both physically and perceptually explore his or her surroundings. Although there is a strong contention that no one setting can provide a person with a source of rest indefinitely, we might also contend that human-nature interactions must be of sufficient duration in order for a person to realize the benefits of that interaction. An examination of the RMT results obtained at longer durations offers some support for this notion.

Results from the RMT showed that as the amount of time to study an image increased, there were subsequent improvements in rates of recognition performance for both scene types. Naturally, we might expect to see such improvements with additional study time. Under these circumstances, the opportunity for a person to purposively direct attention in order to encode images into memory was greater. If all things were then equal, recognition performance for the two scene types would have increased at the same rate (Barrouillet et al., 2004). The data obtained in this study, however, revealed that images perceived high in mystery benefited disproportionately more so across time than low mystery images. These effects seemed particularly pronounced at the longest two presentation durations (i.e., 5 s, 10 s).

Drawing on these results, it would appear that under the right conditions, the presence of mystery in nature had an additive effect on recognition performance. The improvements in recognition performance garnered by high mystery images likely occurred not only because of the mental effort invested, but also because of the salience that features within these types of settings possessed. Attentional control in such instances tends to be more stimulus-driven, or bottom-up oriented (Posner, 1980; Jonides, 1981). This combination of both top-down and bottom-up forms of processing clearly yielded certain direct benefits. In the case of this experiment, participants did not have to spend as much time viewing images perceived high in mystery to obtain the same level of performance they achieved for low mystery images at longer durations. In essence, participants were able to get more of a return on their investment of attention for images perceived high in mystery. Although not characteristically automatic by cognitive standards, the attentional resonance between top-down and bottom-up forms of processing could perhaps give the illusion that a particular task was more effortless in variety.

As further illustration of this notion, a review of Remember response rates by participants provided some interesting points of observation. Within each of the presentation durations, high mystery images tended to elicit more Remember responses than images perceived low in mystery. In addition, the disparity between the Remember response rates for high and low mystery images became even more distinct as the time to study a given image increased. Results obtained from this assessment likely occurred due to the hidden views that were common to images perceived high in mystery. Views of this sort invite a person to look more carefully at their surroundings, perhaps activating a deeper level of processing.

Although previous research has suggested that deeper levels of processing reflect a greater exertion of mental effort (Dewhurst and Hitch, 1999), the data obtained here could offer an alternative perspective that addresses the activation of attention. As participants viewed images perceived high in mystery, the prominent features within these settings captured attention in a more bottom-up fashion. In turn, the engagement of a person's attention conceivably occurred more fully, allowing a person to encode specific details of high mystery images into memory with greater ease.

In an effort to not only examine the effect that mystery in nature had on attention, but also understand why that effect occurred, we carried out tests for mediation. The focus of those examinations revolved around the notion that fascination provides a basis for resting attention (Cimprich, 1992; Kaplan, 1995; Berman et al., 2008). Stimuli perceived as fascinating presumably evoke a form of attention that is more automatic or effortless (Kaplan, 1995; Berto et al., 2008). By avoiding instances that call on directed attention, a person can thus rest that capacity (Kaplan, 1995).

To investigate the extent to which fascination served as a mediating variable, data analysis occurred at the image or item level, as opposed to the participant level. This approach to data analysis was a result of using an independent sample for each study phase. Utilizing an independent sample for each study phase avoided potential tautological problems that might have occurred from having a single sample rate images for certain physical qualities and then testing that sample's recognition memory for the same images. Tests for mediation demonstrated that perceptions of fascination almost fully mediated the effects that scene type had on recognition performance for the two longest durations.

The importance of this finding is twofold. First, in testing for mediation we discovered that fascination was an effective mediator only at longer presentation durations. These results indicate and support our earlier assertion that human-nature interactions likely require sufficient time in order for a person to experience the benefits of those interactions. As a second point of interest, previous conceptualizations of fascination have at times held a position that treats this restorative factor as a form of effortless attention (Kaplan, 1995; Berto, 2005). Drawing on the data obtained from the RMT, the advantages offered by high mystery images were not a result of an absence of effort, but rather the kind of effort a person expended. Discussion around this idea speaks directly to a number of theoretical considerations specific to ART.

THEORETICAL CONSIDERATIONS

In terms of restorative factors, researchers have often thought that fascination plays a critical role in providing a person with the rest that is necessary for attentional recovery (Kaplan, 1995; Berto et al., 2010; Kaplan and Berman, 2010). The significance of this restorative factor stems from James' (1890) delineation between two mechanisms of attention, one of which James argued, did not require effort. Drawing on this notion of attention, Kaplan (1995) adopted the term fascination. Sources of fascination presumably evoke an effortless form of attention that allows directed attention, a capacity that does require effort, to rest (Staats et al., 2003; Felsten, 2009). The data garnered from this study demonstrated that mystery in nature yielded certain attentional advantages as part of carrying out a recognition memory task.

The advantages offered by nature scenes perceived high in mystery were not a result of an absence of effort, but rather the kind of effort a person expended. In viewing scenes that contained environmental patterns related to mystery, the evidence here suggests that this outcome is, in part, a result of the activation of both top-down and bottom-up forms processing. The attentional resonance experienced by a person could perhaps more accurately reflect the direct benefit that person gains from interacting with these types settings. Interacting with settings whereby the patterns of stimulation are both inherently interesting and also parallel to one's goals would seem to have certain advantages.

Consider the distinction often made between hard and soft forms of fascination (Herzog et al., 1997). Experiences of hard fascination tend to embody circumstances in which the stimuli in the environment are so intense they completely consume a person's attention, leaving little opportunity for contemplation. Soft fascination, on the other hand, reflects those circumstances in which the hold on a person's attention is more modest, so as to not preclude a person from thought (Berto et al., 2008). Implicit within this notion of fascination is the understanding that a person is capable of exercising some volition over where she or he may be directing focus. Discussion surrounding these views of fascination provides some perspective from which to interpret the notion of attentional resonance.

In today's society, there is a great deal of disparity between what a person deems important, and what they find inherently interesting. As a result of this difference, many of the tasks a person must perform in everyday life necessitate a form of attention that is more top-down oriented. That is, the processing of information is largely the result of a person allocating attentional resources that are of a limited capacity. On the opposite side of the spectrum, there are countless sources of fascination (e.g., television, smartphones) that can effortlessly capture our attention, but leave us unfilled. Interactions with natural settings, however, tend to offer an appropriate balance between fascinations that modestly capture our attention, and circumstances that still permit a person to act with some volition. In recognition of this notion, it would seem clear that restorative experiences necessitate opportunities where both top-down and bottom-up forms of processing are active.

CONCLUSION

For many people, there is a great deal of enjoyment in discovering that which lies just beyond the realm of their immediate perception. Nature, in all its grandeur, tends to comprise many settings that possess such qualities. The findings obtained from this study indicated that mystery in nature offered certain attention-related benefits. As evidenced, the direct benefit of viewing nature scenes containing mystery was the activation of a less demanding form of attention, which appeared to occur through perceptions of fascination. Extensions to the present study can proceed in variety of directions. Given that this study did not specifically examine the extent to which mystery facilitated attentional recovery, the most logical next step would involve investigating the restorative effects that mystery in nature has on attention. Such efforts would offer the opportunity to evaluate whether memory performance served as a valid indicator for a scene's ability to restore attention. At the same time, these efforts would likely further enhance our understanding of mystery as a scenic quality in nature.

As a scenic quality, mystery comprises one of the four informational variables identified within Kaplan and Kaplan's (1982) environmental preference matrix. Variables such as complexity, coherence, and legibility play an equally important role in influencing a person's preference for an environment (Kaplan, 1987; Stamps, 2004). In fact, previous research has shown that each of the four informational variables, to an extent, correlate with each other (Herzog and Kropscott, 2004; Herzog and Bryce, 2007). In the case of mystery, physical attributes that frequently contribute to a person's perception of mystery (i.e., spatial definition, screening, depth of field etc.) may also enhance the degree to which a person perceives a setting as complex. This potentially unavoidable challenge presents some unique limitations in deciphering the specific influence mystery may have on attention. Future research may wish to explore and further tease out the nuances that contribute to a person's perception of mystery in nature. Efforts directed at this aim may offer a more clear understanding of the effect mystery has on attention.

To better understand the effect that mystery has on attention, focused efforts may seek to also compare mystery in nature with mystery in more urban settings. Previous work has shown that people's perception of mystery is not always favorable under certain conditions (Herzog and Bryce, 2007; Nasar and Jones, 1997). Understanding the influence of mystery in different domains could prove useful from a park planning and design perspective. Finally, with the findings derived from this study, future research might also investigate the role that attentional resonance, a combination or balance of top-down and bottom-up forms of processing, have in the restoration process. Such advancements will not only allow us to better characterize the quality of rest that is so central to the restorative process, but also compel us to uncover the many mysteries and benefits that nature can provide.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.01360/abstract

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The relationship between nature connectedness and happiness: a meta-analysis

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Research suggests that contact with nature can be beneficial, for example leading to improvements in mood, cognition, and health. A distinct but related idea is the personality construct of subjective nature connectedness, a stable individual difference in cognitive, affective, and experiential connection with the natural environment. Subjective nature connectedness is a strong predictor of pro-environmental attitudes and behaviors that may also be positively associated with subjective well-being. This meta-analysis was conducted to examine the relationship between nature connectedness and happiness. Based on 30 samples ($n = 8523$), a fixed-effect meta-analysis found a small but significant effect size ($r = 0.19$). Those who are more connected to nature tended to experience more positive affect, vitality, and life satisfaction compared to those less connected to nature. Publication status, year, average age, and percentage of females in the sample were not significant moderators. Vitality had the strongest relationship with nature connectedness ($r = 0.24$), followed by positive affect ($r = 0.22$) and life satisfaction ($r = 0.17$). In terms of specific nature connectedness measures, associations were the strongest between happiness and inclusion of nature in self ($r = 0.27$), compared to nature relatedness ($r = 0.18$) and connectedness to nature ($r = 0.18$). This research highlights the importance of considering personality when examining the psychological benefits of nature. The results suggest that closer human-nature relationships do not have to come at the expense of happiness. Rather, this meta-analysis shows that being connected to nature and feeling happy are, in fact, connected.

Keywords: nature relatedness, connectedness to nature, happiness, subjective well-being, biophilia, hedonic well-being, meta-analysis, human-nature relationship

INTRODUCTION

Wilson (1984) posits that humans have an inborn tendency to focus on and affiliate with other living things. Termed the *biophilia hypothesis* by Kellert and Wilson (1993), this attraction to life and lifelike processes can be understood through an evolutionary perspective. Because humans have spent almost all of our evolutionary history in the natural environment and have only migrated to urban living in relatively recent times, this attraction, identification, and need to connect to nature is thought to remain in our modern psychology (Kellert and Wilson, 1993). More specifically, it would have been evolutionarily adaptive for our ancestors to be connected to nature in order to survive and thrive in their immediate environmental circumstances. The everyday behaviors of our ancestors such as successfully finding suitable food, water, and shelter, effectively monitoring time and one's spatial location, and avoiding and reacting to predators all heavily relied on paying attention to cues in nature. Thus, individuals who were more connected to the natural world would have had a significant evolutionary advantage over those who were not as connected. To be clear, not all aspects of nature are beneficial and life supporting. For example, Ulrich (1993) reviews instances of *biophobia*, or a biological preparedness to acquire fear of persistently threatening things such as snakes and spiders. Nonetheless, he argues that evidence of biophobia simultaneously suggests the viability of evolved positive responses to the natural world. Evolutionary psychology more generally suggests that modern environments are not optimally suited to minds that evolved in different (more natural) environments (e.g., Barkow et al., 1992; Buss, 2000). Thus, the specific *biophilia* hypothesis is not needed to retain the more general evolutionary idea of modern gaps in optimal human-environment fit.

The gap in nature exposure between our early evolutionary environments and modern life is clear, and appears to be growing. For instance, children are spending less time playing in natural environments compared to previous generations (Clements, 2004; Louv, 2005; England Marketing, 2009) and, in general, individuals from developed nations are spending almost all of their time indoors (Evans and McCoy, 1998; MacKerron and Mourato, 2013). On a broader scale, for the first time in human history, more of the world's population now lives in urban instead of rural areas (United Nations Population Division, 2002). This physical disconnection from the environments in which we evolved in may be having a detrimental impact on our emotional well-being as exposure to nature is associated with increased happiness (Berman et al., 2008, 2012; Mayer et al., 2009; Nisbet and Zelenski, 2011; MacKerron and Mourato, 2013; White et al., 2013).

Beyond these trends, individuals vary along a continuum in their subjective connection to nature (e.g., Mayer and Frantz, 2004). This individual difference, which will be referred to as nature connectedness, can be thought of as trait-like in that it is relatively stable across time and situations (Nisbet et al., 2009). Nevertheless, one's subjective connection to nature can fluctuate (e.g., compare taking a walk outside in nature vs. indoors through tunnels) and be measured at the state level as well (Schultz, 2002; Nisbet and Zelenski, 2011). For the purposes of this paper, nature connectedness will be primarily conceptualized as a trait-like between-person difference.

Consistent personality, attitudinal, behavioral, and well-being differences are found between those who strongly identify with and feel connected to the natural world compared to those who do not. Individuals higher in nature connectedness tend to be more conscientious, extraverted, agreeable, and open (Nisbet et al., 2009; Tam, 2013a). Beyond personality traits, a greater connection to nature is also associated with more pro-environmental attitudes, a greater willingness to engage in sustainable actions, and increased concern about the negative impact of human behavior on the environment (Mayer and Frantz, 2004; Leary et al., 2008; Nisbet et al., 2009; Tam, 2013a). Behaviorally, individuals higher in nature connectedness are more likely to spend time outdoors in nature and engage in a variety of pro-environmental behaviors (e.g., buy "green" products; Mayer and Frantz, 2004; Nisbet et al., 2009; Tam, 2013a). Most relevant to this article, nature connectedness has also been correlated with emotional and psychological well-being (e.g., Nisbet and Zelenski, 2013). The purpose of the current research was to examine the relationship between nature connectedness and happiness in particular by conducting a meta-analysis. The meta-analysis was completed by using correlations to examine the strength of the relationship but not necessarily if one variable causes the other.

An evolutionary history where it was apparently advantageous for our ancestors to be connected to nature and present day variability in nature connectedness appear to be contradictory ideas at first glance, but multiple explanations exist for how both can co-exist. First, similar to how variability in other personality traits can be understood as being the result of cost and benefit trade-offs for fitness (Nettle, 2006), so too can nature connectedness. For example, although conscientiousness is often thought of as a desirable and beneficial personality trait (e.g., it is positively associated with longevity; Friedman et al., 1995), there are certain circumstances where being high in conscientious would be evolutionarily disadvantageous (e.g., missing out on unexpected short-term opportunities; Nettle, 2006). Relatedly, there may have been ways in which being high in nature connectedness was not evolutionarily advantageous (e.g., refusing to kill/eat an animal for sustenance or being too comfortable and not having a reasonable amount of fear of a dangerous predator).

Taking another perspective, although we might have an innate predisposition to connect and identify with the natural world, it may be shaped by early childhood experiences and culture. Orr (1993) raised the idea that there may be a critical period during development where one must have positive experiences in nature in order to develop biophilic beliefs, feelings, and tendencies. In addition, Kellert (1997) believed that biophilia could also be shaped by culture and experiences despite it being inborn. Supporting this, individuals who are higher in nature connectedness as adults recall spending more time in nature during their childhood compared to those who are not as connected to nature (Tam, 2013a). In addition, researchers have found that some groups (e.g., Menominee Native Americans) are more likely to view humans as a part of nature and feel psychologically closer to nature compared to other groups (e.g., European Americans), even at relatively early stages in development (e.g., Bang et al., 2007; Unsworth et al., 2012). This research illustrates that developmental experiences and cultural context can have an influence on our evolved tendency to connect with nature. In sum, the biophilia hypothesis and individual differences in nature connectedness are not contradictory and can logically co-exist to examine and explain the human-nature relationship.

A variety of concepts and measures have been developed in order to assess the human-nature relationship, including commitment to nature (Davis et al., 2009), connectedness to nature (Mayer and Frantz, 2004), connectivity with nature (Dutcher et al., 2007), emotional affinity toward nature (Kals et al., 1999), environmental identity (Clayton, 2003), inclusion of nature in self (Schultz, 2001), and nature relatedness (Nisbet et al., 2009). Through the lens of interdependence theory (Rusbult and Arriaga, 2000), Davis et al. (2009) defined commitment to nature as a "psychological attachment to and long-term orientation toward the natural world" (p. 174) and adapted the commitment scale by Rusbult et al. (1998) which originally assessed commitment to a close partner. Mayer and Frantz (2004) described connectedness to nature as a "measure of an individuals' trait levels of feeling emotionally connected to the natural world" (p. 503) and is explicitly conceptualized as assessing the affective component of the human-nature connection. Another clearly affective nature connectedness construct is emotional affinity toward nature, which was developed by Kals et al. (1999) and involves pleasant feelings of inclination toward nature such as oneness and love. Inclusion of nature in self was developed by Schultz (2001) who adapted the Inclusion of Other in Self scale (Aron et al., 1992) in order "to measure the extent to which an individual includes nature within his or her cognitive representative of self" (Schultz and Tabanico, 2007, p. 1221). With one of its items being the Inclusion of Nature in Self scale, connectivity with nature is defined by Dutcher et al. (2007) as "a sense of sameness between the self, others, and nature" (p. 474). The multidimensional construct of environmental identity, which Clayton (2003) likens to other collective identities that people have, is conceptualized as a feeling of connection to the natural environment and the belief that the environment is an important part of one's self-concept. Lastly, nature relatedness is another multidimensional construct that involves one's "affective, cognitive, and physical relationship with the natural world" (Nisbet et al., 2009, p. 719).

Despite these different concepts and measures, they all appear to be assessing slightly different expressions of the same underlying construct (i.e., one's subjective connection to nature). To support this, they are all highly correlated with one another and associated with other personality characteristics, measures of well-being, and environmental attitudes and behaviors in a relatively similar manner (see Tam, 2013a). For these reasons, no distinctions will be made between these concepts in this paper and nature connectedness will be used as an umbrella term for all of them.

A common line of research for many in this area is the investigation of the relationship between nature connectedness and well-being (e.g., Mayer and Frantz, 2004; Howell et al., 2011; Nisbet and Zelenski, 2011). Well-being and the path to its attainment have traditionally and typically been conceptualized in one of two ways by philosophers and psychologists (Grinde, 2012). From a hedonic perspective, well-being consists of the pleasantness of an individual's experiences and is achieved through the maximization of pleasure and the satisfaction of desires (Kahneman, 1999; Fredrickson, 2001). Subjective well-being, another term for happiness in the hedonic approach, consists of an affective component (i.e., the presence of positive emotional experiences and the absence of negative ones) and a cognitive component (i.e., the evaluation of one's life as satisfying; Diener and Lucas, 1999; Diener, 2009). Specific measures used to assess hedonic well-being include the Positive and Negative Affect Schedule (Watson et al., 1988), the Subjective Happiness Scale (Lyubomirsky and Lepper, 1999), and the Satisfaction with Life Scale (Diener et al., 1985). In contrast, from a eudaimonic perspective, well-being is more about following one's deeply held values and realizing one's fullest potential (Waterman, 1993; Ryff, 1995). As an example, psychological well-being is a construct that is thought to constitute eudaimonic well-being and consists of six facets of actualization including mastery, life purpose, autonomy, self-acceptance, positive relatedness, and personal growth (Ryff and Keyes, 1995). Despite the contentious history between these two perspectives, hedonic and eudaimonic well-being indicators tend to be positively correlated and can influence one another implying that they are not mutually exclusive but overlapping and distinct (King et al., 2006; Waterman, 2008; Huta and Ryan, 2010). Furthermore, individuals high in hedonic and eudaimonic motives tend to experience the greatest amount of overall well-being and are considered to be flourishing (Huta and Ryan, 2010; Forgeard et al., 2011). Nonetheless, due to its more targeted definition, established assessment tools, and common usage compared to the eudaimonic approach (Kashdan et al., 2008), this meta-analysis primarily focused on hedonic measures of well-being.

Although events can influence an individual's present mood state, most have only a limited long-term impact on one's happiness (Steel et al., 2008, but see Diener et al., 2006 for exceptions). In fact, subjective well-being tends to be relatively stable over time (Diener and Lucas, 1999; Lyubomirsky et al., 2005; Nes et al., 2006). Relatedly, subjective well-being is associated with particular personality traits. Similar to nature connectedness, subjective well-being is consistently positively associated with extraversion, agreeableness, and conscientiousness, but unlike nature connectedness it is also negatively correlated with neuroticism (Steel et al., 2008). Lastly, subjective well-being can predict important life outcomes such as health, longevity, and disease (Williams and Schneiderman, 2002; Lyubomirsky et al., 2005; Chida and Steptoe, 2008).

There are several reasons why one would expect nature connectedness to be positively associated with subjective well-being. First, being and feeling connected in general consistently predicts well-being (Ryan and Deci, 2001). For instance, consider social connectedness. A rich and fulfilling social life is a commonality found in the lives of very happy people (Diener and Seligman, 2002). Relatedly, those who are higher in the personality traits of extraversion and agreeableness tend to experience more positive emotions compared to those who are lower in these characteristics (Steel et al., 2008). Within individuals, daily fluctuations in feelings of social relatedness predict changes in subjective well-being (Reis et al., 2000). In contrast, loneliness and shyness are negatively correlated with happiness (Booth et al., 1992) and social exclusion has been found to activate similar brain regions as physical pain (Eisenberg et al., 2003). These findings have led some to argue that social connectedness is a prerequisite for happiness and a basic human need (Baumeister and Leary, 1995). Having a connection with nature may function similarly and also promote well-being. It is important to note that there appears to be something else beyond mere general subjective connectedness which explains nature connectedness' relationship with happiness. When one controls for other connections (e.g., family or culture), nature connectedness still significantly predicts happiness (Zelenski and Nisbet, 2014).

Additionally, individuals who are higher in nature connectedness may seek out more opportunities to reap the psychological benefits associated with nature exposure, or, from a biophilia perspective, satisfy the need to affiliate with other living things. In support of this, nature connectedness is positively associated with nature contact (e.g., frequency of time spent outdoors and in nature) and interaction with other living things (e.g., pet ownership; Nisbet et al., 2009), and there is a substantial amount of evidence that shows that exposure to nature leads to increased happiness (Berman et al., 2008, 2012; Mayer et al., 2009; Nisbet and Zelenski, 2011; White et al., 2013).

There are also plausible reasons to expect an effect in the opposite direction. As previously mentioned, nature connectedness consistently predicts pro-environmental attitudes and concern about the environment (Mayer and Frantz, 2004; Leary et al., 2008; Nisbet et al., 2009; Tam, 2013a). Individuals who incorporate nature into their sense of self may view harm done to nature as harm done to themselves (Mayer and Frantz, 2004). As knowledge, awareness, certainty, and salience concerning the negative impacts that climate change will have on the environment and life on Earth increase, being more connected to nature could conceivably hamper happiness instead of promoting it (Doherty and Clayton, 2011). In fact, a quarter of Americans feel depressed or guilty about the issue of global warming and those who are most alarmed about climate change are more likely to feel afraid, angry, sad, and disgusted (Maibach et al., 2009). The term *eco-anxiety* has even been used by some in the media to reflect the worry and concern about global warming that some individuals have, along with self-reported symptoms of sleeplessness, loss of appetite, weakness, irritability, and panic attacks (Nobel, 2007). Furthermore, models of grieving and mourning following a loss have been applied to individuals' reaction to learning about and accepting global warming and making changes in lifestyle to minimize one's carbon footprint (Randall, 2009). Given the greater environmental concern that seems to accompany a subjective connection to nature, negative emotions and distress may be more frequently experienced by those higher in nature connectedness. From this perspective, one might predict that nature connectedness might be negatively associated with happiness. It is also possible that there is no relationship between one's subjective connection to nature and subjective well-being (e.g., because the positive and negative processes cancel each other, on average).

Although a previous meta-analysis has been published that examined whether exposure to natural environments has a positive impact on health and well-being (Bowler et al., 2010), no meta-analyses have been conducted that have comprehensively investigated whether the trait of nature connectedness is associated with happiness. The purpose of this study was to test whether the relationship between these two constructs was significant, to provide an estimate of its effect, and to determine whether there was significant variability across samples. This is necessary as the association between measures of nature connectedness and happiness appear to vary considerably, with correlation coefficients ranging from −0.01 (Nisbet et al., 2011) to 0.42 (Zelenski and Nisbet, 2014) in the published research literature. We hypothesized that there would be a small but significant relationship between nature connectedness and happiness. This was a realistic estimate as it tends to be the average or median effect size in many areas of psychology (Sarason et al., 1975; Lipsey and Wilson, 1993; Richard et al., 2003).

In addition, moderator analyses were conducted on publication status, year, age, gender, type of happiness, and measure of nature connectedness. Publication status was analyzed as a moderator in order to determine if there is a publication bias in this area of research (i.e., published studies reporting a stronger relationship between nature connectedness and happiness compared to unpublished ones). Year was analyzed as a moderator because of the recent attention given to the decline effect—the observation that many scientific findings diminish with time (Schooler, 2011). Age and gender were analyzed as moderators because being older and being female tend to be associated with higher environmental concern, attitudes, and behaviors (e.g., Grønhøj and Thøgersen, 2009; Scannell and Gifford, 2013). In order to examine whether the different measures of well-being and nature connectedness accounted for any of the variability across samples, separate meta-analyses were run for the most common types of happiness (i.e., positive affect, life satisfaction, and vitality) and nature connectedness (i.e., connectedness to nature, inclusion of nature in self, and nature relatedness).

METHODS

INCLUSION AND EXCLUSION CRITERIA

To be included in this meta-analysis, studies had to employ at least one measure of nature connectedness and at least one measure of happiness, and report on their relationship. Only explicit self-report trait measures of identification with nature were included (see **Table 1**). In contrast, implicit or state measures of nature connectedness were excluded in order to minimize commensurability (i.e., grouping substantially different measures together; Sharpe, 1997; Cortina, 2003). For instance, the average correlation between explicit self-report measures and the implicit association task is 0.24, which is substantially lower than the correlations found between explicit measures of nature connectedness (Hofmann et al., 2005; Tam, 2013a). In addition, state nature connectedness was excluded because a previous meta-analysis has already examined the impacts of nature exposure on emotional functioning (Bowler et al., 2010). Studies that artificially dichotomized nature connectedness were excluded as well to avoid all the problems that are associated with the dichotomization of quantitative variables (see MacCallum et al., 2002).

Table 1 | Nature connectedness measures included in meta-analysis.

Measure	Citation	Sample number
Allo-inclusive identity	Leary et al., 2008	4.2, 5.1, 6
Commitment to nature	Davis et al., 2009	18.1
Connectedness to nature	Mayer and Frantz, 2004	3.1, 3.2, 3.5, 4.1, 4.2, 5.1, 5.2, 7.4, 15, 18.1, 19, 20.1, 20.2
Connectedness with nature—single item	Cervinka et al., 2012	3.1, 3.2, 3.5
Connectivity to nature	Dutcher et al., 2007	18.1
Emotional affinity toward nature	Kals et al., 1999	18.1
Environmental identity	Clayton, 2003	18.1
Inclusion of nature in self	Schultz, 2001	9, 16, 17.4, 18.1, 21.1a, 21.1b
Nature relatedness	Nisbet et al., 2009	1, 2a, 2b, 4.2, 5.1, 8, 9, 10, 11, 12, 13, 14.1, 14.2, 18.1, 21.1a, 21.1b, 21.2

*See **Table 3** for studies associated with each sample number.*

Regarding the second construct of interest, studies that employed either explicit self-report state or trait measures of subjective well-being were included in the meta-analysis (see **Table 2**). Studies that measured eudaimonic well-being (e.g., self-acceptance), hedonistic values, or implicit measures of happiness were excluded in order to reduce commensurability and maintain a targeted focus on hedonic well-being. Nevertheless, vitality, which is defined as the positive feeling of being alive, alert, and energetic (Ryan and Frederick, 1997), was included in the current meta-analysis. Although it is theoretically conceptualized as a eudaimonic construct and is associated with other measures of eudaimonic well-being (e.g., self-actualization; Ryan and Frederick, 1997), subjective vitality is predicted by both hedonic and eudaimonic motives (Huta and Ryan, 2010), as well as hedonic behaviors (but not eudaimonic ones; Henderson et al., 2013). Furthermore, there appears to be similar conceptual overlap between vitality and some of the other high arousal positive emotions included in measures such as the Positive Affect and Negative Affect Scale (e.g., excited, enthusiastic, alert, attentive, and active; Watson et al., 1988). For these reasons, measures of vitality were included in this meta-analysis. As the focus of this meta-analysis is on positive emotional functioning,

Table 2 | Happiness measures included in meta-analysis.

Measure	Citation	Sample number
Affect-adjective scale	Diener and Emmons, 1985	1, 2b
Calm, contentment, and peacefulness—single item	Nisbet, 2013a,b	11, 12
Current mood scale from the multidimensional comfort questionnaire	Steyer et al., 1997	3.1
Emotional well-being	Keyes, 2005	4.1, 4.2, 5.1, 5.2
Happy—single item	Ajzen and Driver, 1992	17.4
Nature positive affects	Nisbet, 2011	9, 10, 21.1a, 21.1b, 21.2
Percent happy	Fordyce, 1988	9
Positive and negative affect schedule	Watson et al., 1988	8, 9, 10, 13, 14.1, 14.2, 15, 19, 21.1a, 21.1b, 21.2
Satisfaction with life scale	Diener et al., 1985	1, 2a, 2b, 3.2, 6, 7.4, 9, 13, 14.1, 14.2, 16, 18.1, 19, 21.1a, 21.1b, 21.2
Scale of positive and negative experience	Diener et al., 2010	20.1, 20.2
Steen happiness index	Seligman et al., 2005	5.1, 5.2
Subjective happiness scale	Lyubomirsky and Lepper, 1999	9, 13, 18.1, 21.1a, 21.1b, 21.2
Subjective vitality scale	Ryan and Frederick, 1997	8, 9, 10, 13, 20.1, 20.2, 21.1a, 21.1b, 21.2
Vital, energetic, and enthusiastic—single item	Nisbet, 2013a,b	11, 12
Vitality scale from the short form (36) health survey	Bullinger and Kirchberger, 1989	3.5, 15

*See **Table 3** for studies associated with each sample number.*

measures of negative affect were excluded. Studies that artificially dichotomized happiness were excluded as well due to the dichotomization problems that were previously alluded to.

All age groups were included as eligible samples because there was no theoretical or practical reason to exclude any in particular. For this same reason, no exclusions were made based on the country where the study was conducted, the language it was written in, or the time when it was conducted. Relatedly, the study had to provide sufficient information to code an effect size and its variance (i.e., correlation coefficient and sample size) to be included. Qualitative studies were excluded and samples sizes had to be above 10 to be included. Lastly, experimental designs were included only if they provided a baseline measure of the relationship between connectedness to nature and happiness prior to any experimental manipulations.

SEARCH STRATEGIES

Numerous methods were used to identify studies. Abstracts were searched in the *PsycINFO* and *Dissertation and Theses Full Text* electronic databases using the various names given for nature connectedness as the search terms: commitment to nature, connectedness to nature, connectivity with nature, emotional affinity toward nature, environmental identity, inclusion of nature in self, and nature relatedness. Reference lists of studies that met the inclusion/exclusion criteria were investigated, as well as the studies that cited them. Authors who conducted studies that measured nature connectedness and happiness but did not report on their relationship were contacted to obtain the necessary statistical information. Requests for additional findings were sent out in May 2013 using the email listserv for Division 34 of the American Psychological Association and in June 2013 using the Conservation Psychology email listserv.

CODING PROCEDURE

A standard coding form and explicit rules outlined in a coding manual that was developed for the current meta-analysis were used for each sample (see Supplementary Material). The standard coding forms contained a cover sheet that was completed for each non-overlapping sample, along with a basic study descriptives form and a sample information form. Specific effect sizes were coded on individual effect size forms. If a sample had multiple measures of nature connectedness and/or happiness, a weighted average of the effect sizes was calculated for that sample. In total, 140 effect sizes were coded from the 30 unique samples with each sample having its own overall effect size. These were used in subsequent analyses in order to ensure that the independence of observations principle was maintained.

Interrater reliability analyses were conducted on all of the non-overlapping samples by the first and second authors. The first author developed the coding manual and coded all of the studies, and then trained the second author as the secondary coder. Minor clarifications and updates were made to the coding manual after the two coders compared their coding of the first couple of studies. The raters coded all of the studies separately and then had multiple meetings where disagreements were identified and consensus ratings were reached.

The two raters coded 124 common effect sizes with high levels of agreement (absolute intraclass correlation [ICC] based on single rater = 0.99). Eleven effect sizes were coded by the first author but not the second and an additional five effect sizes were coded by the second author but not the first. Out of the 140 effect sizes coded by the raters, a consensus was reached that 127 of them should be included in the meta-analysis. High levels of agreement were also found for the other continuous variables that were coded (i.e., year, sample size, percentage of females, and average age of sample), with ICC values ranging from 0.98 to 1.0. When possible, Cohen's Kappa was computed for the categorical variables ($n = 28$) and were found to range from 0.21 to 1 ($M = 0.91$). Following conventions outlined in Landis and Koch (1977), the strength of agreement was almost perfect (i.e., above 0.80) for the vast majority of the categorical variables ($n = 24$) and substantial (i.e., between 0.60 and 0.80) for all the rest of them excluding one. The coding of the happiness measure as state, trait, or mixed had the uniquely low interrater reliability of 0.21. Nonetheless, the overall percent agreement for the coding of this variable was 87.90% and the majority of disagreements occurred early on in the coding process before clarifications were made to the coding manual or due to a rater forgetting to code this variable and leaving it blank. In general, the interrater reliability was relatively high which supports the notion that other raters who followed the same coding manual would code the samples in a consistent manner and end up with similar results.

STATISTICAL METHODS

Effect size

Because the relationship between two continuous variables was being examined, correlation coefficients were the effect size used to summarize the relationship between nature connectedness and happiness in this meta-analysis. Because some of the correlation coefficients were expected to be above 0.30, correlation coefficients were transformed into Fisher's Z values before being meta-analyzed. This transformation ensured that the variance of the effect size would be solely based on the sample size and not the magnitude of the effect size as well (Borenstein et al., 2009). For ease of interpretation, all the results involving Fisher's Z values have been retransformed into correlation coefficients. Following the conventions outlined in Cohen (1988), correlation coefficients of 0.10 were considered small, 0.30 were considered moderate, and 0.50 were considered large.

Aggregation of findings

Both fixed-effect and random-effects meta-analyses were conducted (Borenstein et al., 2009). The fixed-effect model assumes that there is one true effect size and that variability across samples is sampling error. The random-effects model assumes that there is no one true effect size, but a distribution of effect sizes, and variability across samples is real and not just sampling error. The random-effects model allows one to generalize beyond the samples included in the meta-analysis, while the fixed-effect model does not. Despite its advantages, the random-effects model is a more conservative test and unstable when the number of samples is smaller than 30 (Overton, 1998; Schulze, 2007). Both fixed-effect and random-effects meta-analyses were conducted in order to account for the advantages and disadvantages of each and increase confidence in consistent results. Regardless of the model, the effect size of each sample was weighted by the inverse of its variance.

Cochran's Q statistic was computed to determine whether there was significantly more variability across samples than what one would expect by chance (Borenstein et al., 2009). To determine the percentage of variability across samples that is beyond what one would expect by chance, I^2 was obtained. Following recommendations outlined in Higgins et al. (2003), an I^2 value of 25% was considered low variability, 50% was considered moderate, and 75% was considered high.

Because outliers can distort the results of a meta-analysis, extreme effect sizes were identified by following the rules developed in Hanson and Bussière (1998). First, the effect size must be either the highest or lowest in magnitude. Second, Cochran's Q statistic must be significant. Third, the effect size must account for more than half of Q. Fourth, there must be more than three samples. If a potential outlier was found, the results with and without that sample were reported but interpretations were based on the latter. A sample with an extremely large sample size relative to the rest of the samples can also have a large impact on the results of a meta-analysis. Following the rule used in other meta-analyses (e.g., Helmus et al., 2013), the weight of the largest sample was reduced to be only 50% larger than the weight of the second largest sample if the variability across samples was found to be significant.

Moderator analyses

For categorical moderators, fixed-effect between-level Q moderator analyses were conducted (Borenstein et al., 2009). The between-level Q was obtained to determine whether the moderator significantly accounted for the unexplained variability across samples. Fixed-effect was chosen because moderator analyses tend to have low power and fixed-effect moderator analyses provide more power than random-effects. In addition, the Q statistic is easier to interpret in fixed-effect models. For continuous moderators, fixed-effect meta-regression was conducted (Borenstein et al., 2009). Meta-regression was conducted to determine whether the moderator is a significant predictor of effect size. Fixed-effect assumes that the moderators completely explain the effect size of the samples and that there is no residual heterogeneity. It was chosen over random-effects because of its higher power.

RESULTS

OVERVIEW OF INCLUDED STUDIES

As of August 2nd, 2013, 30 non-overlapping samples from 21 studies were identified. Descriptive information for each of the included samples can be found in **Table 3**. The total sample size was 8523. The sample sizes ranged from 22 to 2224 ($M = 284.10$, $SD = 384.47$, $Mdn = 215$). Many of the samples came from Canada (46.7%), followed by the United States (20%), Europe (10%), Asia (3.3%), and mixed locations (10%). All the studies were written in English. The samples ranged in average age from 19.48 years to 63.42 years ($M = 31.91$, $SD = 11.37$). The percentage of females in each sample ranged from 38.62 to 86.10% ($M = 65.33$, $SD = 11.84$). University/college students made up 33.3% of the samples, while 40% of samples were community members and 6.7% of samples contained a mix. The years of the studies ranged from 2004 to 2014. Samples were coded as published if they came from a journal article or book chapter. Using this criterion, 60% of the samples were published and 40% were unpublished. Samples were coded as peer reviewed if they came from a dissertation/thesis or journal article. Using this criterion, 73.3% of the samples were peer-reviewed and 26.7% were not.

OVERALL EFFECT SIZE AND STATISTICAL SIGNIFICANCE

Figure 1 is a forest plot which shows the effect size and confidence interval associated with each sample and the meta-analytic average from the fixed-effect meta-analysis. **Table 4** shows the results of both the fixed-effect and random-effects meta-analysis. As one can see, both models produced relatively consistent results. More specifically, a small mean weighted effect size was found between nature connectedness and happiness in the fixed-effect [$r = 0.19$, 95% CI (0.16, 0.21), $k = 30$, $n = 8523$] and random-effects models [$r = 0.18$, 95% CI

Table 3 | Descriptive information for included samples.

Sample number	Study	*N*	Location	Mean age (years)	% Female	Published
1	Aitken and Pelletier, 2013a	272	Canada	–	–	No
2a	Aitken and Pelletier, 2013b	189	Canada	–	–	No
2b	Aitken and Pelletier, 2013b	369	Canada	–	–	No
3.1	Cervinka et al., 2012	94	Europe	37.30	57.40	Yes
3.2	Cervinka et al., 2012	119	Europe	36.00	52.10	Yes
3.5	Cervinka et al., 2012	101	Europe	34.30	54.50	Yes
4.1	Howell et al., 2011	437	Canada	22.17	69.40	Yes
4.2	Howell et al., 2011	262	Canada	20.39	68.00	Yes
5.1	Howell et al., 2013	311	Canada	22.07	68.00	Yes
5.2	Howell et al., 2013	227	Canada	23.29	63.00	Yes
6	Leary et al., 2008	148	–	–	–	Yes
7.4	Mayer and Frantz, 2004	135	USA	36.00	65.93	Yes
8	Nisbet, 2005	354	Canada	20.03	59.90	No
9	Nisbet, 2011	207	Mixed	27.81	77.80	No
10	Nisbet, Unpublished data	22	–	–	–	No
11	Nisbet, 2013a	2,225	Canada	45.76	83.80	No
12	Nisbet, 2013b	341	Canada	46.79	86.10	No
13	Nisbet, Unpublished data	110	–	–	–	No
14.1	Nisbet et al., 2011	184	Canada	19.48	67.40	Yes
14.2	Nisbet et al., 2011	145	Canada	42.37	38.62	Yes
15	Okvat, 2011	50	USA	63.42	84.00	No
16	Reist, 2004	357	Mixed	36.42	66.00	No
17.4	Schultz and Tabanico, 2007	39	USA	–	67.50	Yes
18.1	Tam, 2013a	322	Asia	20.36	45.34	Yes
19	Trull, 2008	66	Canada	–	56.06	No
20.1	Wolsko and Lindberg, 2013	265	USA	30.11	62.90	Yes
20.2	Wolsko and Lindberg, 2013	223	USA	33.30	61.40	Yes
21.1a	Zelenski and Nisbet, 2014	331	Canada	20.50	73.10	Yes
21.1b	Zelenski and Nisbet, 2014	415	Mixed	32.20	79.70	Yes
21.2	Zelenski and Nisbet, 2014	204	USA	–	60.00	Yes

Samples were given numbers based on their order in the reference list. If there were multiple studies within the same paper, the numbers to the right of the decimal indicate which specific study the sample came from. Letters indicate that there were multiple samples within the same study. For example, study number 21.1b indicates that it was the second sample within the first study of the twenty-first paper. The sample size for each sample is the one associated with its overall/averaged effect size.

(0.15, 0.22), $k = 30$, $n = 8523$]. Because both of the 95% confidence intervals did not include zero, one can conclude that this small mean weighted effect size was significant at the $p < 0.05$ level.

ANALYSIS OF HETEROGENEITY

The variability across samples was significant ($Q = 64.29$, $df = 29$, $p < 0.001$) and the I^2 indicated that 54.89% of the observed variability was beyond what would be expected by chance. In other words, it would be reasonable to conclude that there was a moderate amount of variability across samples. This implies that there may be some variables moderating the magnitude of the effect size.

OUTLIERS AND EXTREMELY LARGE SAMPLES

Following the rules developed in Hanson and Bussière (1998), no outliers were identified. Although Cochran's Q was significant and there were more than three samples, the samples with the highest and lowest effect sizes did not account for more than half of the Q statistic. When the sample with the lowest effect size (Schultz and Tabanico, 2007; $r = -0.13$) was removed from the meta-analysis, the Q statistic did not decrease by 50% ($Q = 60.76$). Relatedly, when the sample with the highest effect size (Nisbet, Unpublished data; $r = 0.50$) was removed from the meta-analysis, the Q statistic did not decrease by 50% ($Q = 61.83$). For these reasons, all the samples identified were included in the overall meta-analysis.

Nisbet (2013a) can be considered an extremely large sample as it contributed over a quarter of the total participants in this meta-analysis and its sample weight was more than five times the size of the second largest weight (2221 vs. 434). Following the rules outlined in the methods section, the sample weight of Nisbet (2013a) was artificially reduced to be only 50% larger than the second largest sample weight (i.e., 651). This is what was used in the overall meta-analysis and the moderator analyses.

INVESTIGATION OF POTENTIAL MODERATORS

Moderator analyses were conducted to examine whether publication status, gender, year, age, type of happiness, and measure of nature connectedness accounted for the significant variability across samples.

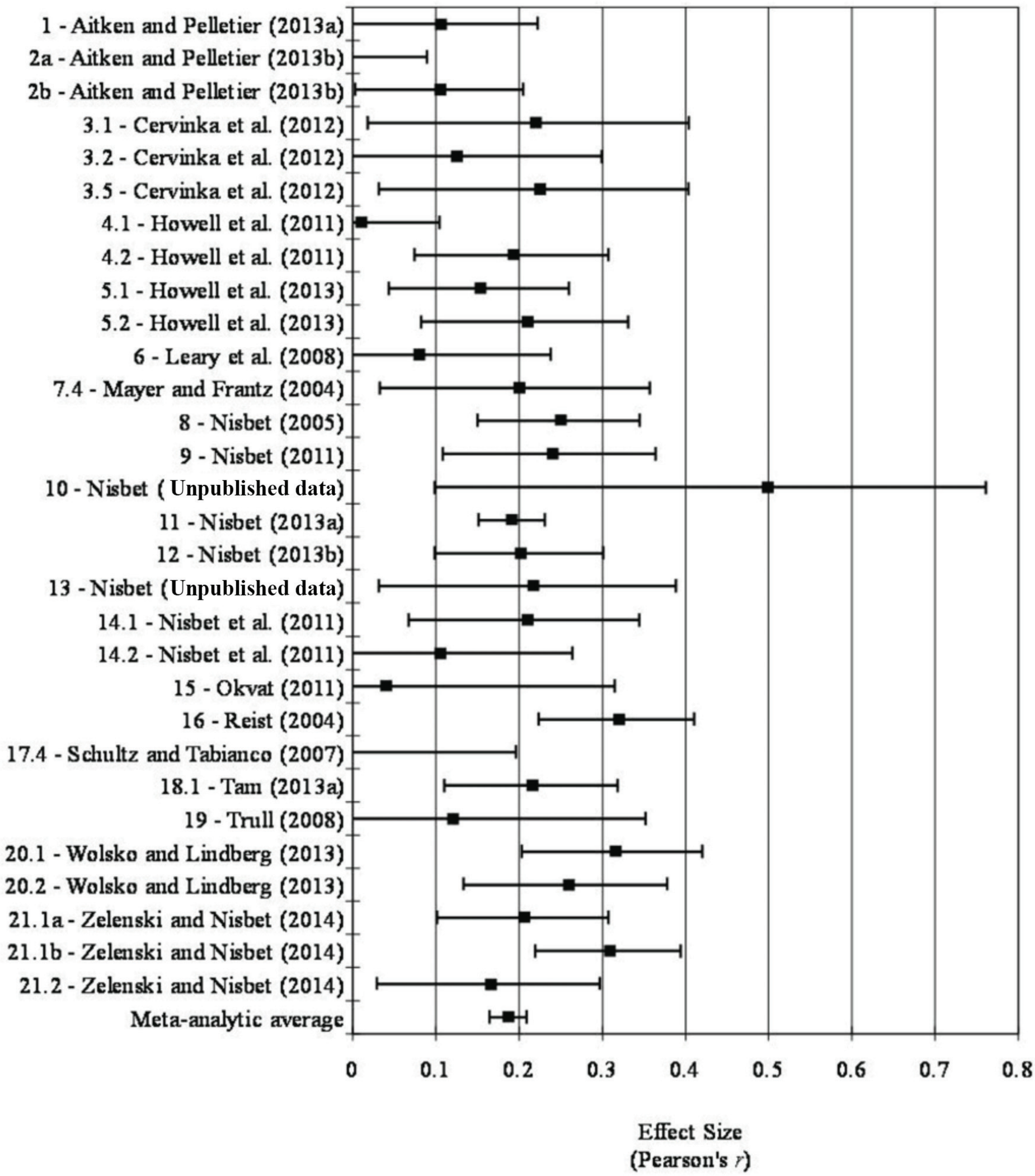

FIGURE 1 | Forest plot.

Table 4 | Meta-analysis results.

Fixed-effect			Random-effects						
	95% CI			95% CI					
r	*LL*	*UL*	*r*	*LL*	*UL*	*Q*	I^2 (%)	*k*	*n*
0.19	0.16	0.21	0.18	0.15	0.22	64.29***	54.89	30	8523

$^{***}p < 0.001$.

Publication status

To examine whether there was a publication bias, fixed-effect between-level Q moderator analyses were run with publication status (i.e., published vs. unpublished) as the categorical moderator. **Table 5** shows the results of this moderator analysis. Because the between-level Q statistic is distributed as a chi-square with the degrees of freedom being the number of levels of the categorical variable minus one, the critical value for this moderator analysis is 3.84 for $p < 0.05$ at a degrees of freedom of 1. As the between-level Q did not exceed the critical value (between-level $Q = 0.01$, $df = 1$, $p = 0.92$), one can conclude that publication bias is probably not an issue for this research topic.

Gender

In order to investigate whether gender moderates the relationship between nature connectedness and happiness, a fixed-effect meta-regression was conducted with percentage of females in the sample as the predictor variable. Percentage of females in the sample was not a significant predictor of effect size (slope $= 0.0004$, $SE = 0.00113$, $Z = 0.35$, $p = 0.73$, $k = 24$, $n = 7413$).

Year

In order to investigate whether the relationship between nature connectedness and happiness is influenced by the year, fixed-effect meta-regressions were conducted with year as the predictor variable. Year was not a significant predictor of effect size (slope $= -0.00479$, $SE = 0.00412$, $Z = -1.16$, $p = 0.25$, $k = 30$, $n = 8523$). Thus, one can conclude that the decline effect is probably not an issue for this research topic.

Age

In order to examine whether the relationship between nature connectedness and happiness stays the same throughout the lifespan, fixed-effect meta-regressions were conducted with average age of the sample as the predictor variable. Average age was not a significant predictor of effect size (slope $= 0.00064$, $SE = 0.00134$, $Z = 0.48$, $p = 0.63$, $k = 21$, $n = 7104$).

Type of happiness

The relationship between nature connectedness and happiness may depend on how happiness is defined and measured. Because some of the samples used multiple measures of happiness, conducting moderator analyses on this variable would violate the principle of independence. For this reason, general patterns were observed by conducting separate meta-analyses for the three main types of happiness in this study: positive affect, life satisfaction, and vitality. Samples that did not contain a particular type of happiness measure were excluded from that respective meta-analysis and overall effect sizes for each type were calculated for the remaining samples. Both fixed-effect and random-effects meta-analyses were conducted.

Positive affect. A small mean weighted effect size was found between nature connectedness and positive affect in the fixed-effect [$r = 0.22$, 95% CI (0.19, 0.25), $k = 19$, $n = 5926$] and random-effects models [$r = 0.22$, 95% CI (0.17, 0.26), $k = 19$, $n = 5926$]. The variability across samples was significant ($Q = 40.69$, $df = 18$, $p = 0.002$) and moderate as the I^2 indicated that 55.77% of the observed variability was beyond what would be expected by chance.

Life satisfaction. A small mean weighted effect size was found between nature connectedness and life satisfaction in the fixed-effect [$r = 0.17$, 95% CI (0.14, 0.20), $k = 16$, $n = 3575$] and random-effects models [$r = 0.16$, 95% CI (0.11, 0.20), $k = 16$, $n = 3575$]. The variability across samples was significant ($Q = 32.17$, $df = 15$, $p = 0.006$) and moderate as the I^2 indicated that 53.37% of the observed variability was beyond what would be expected by chance.

Vitality. A small mean weighted effect size was found between nature connectedness and vitality in the fixed-effect [$r = 0.24$, 95% CI (0.21, 0.27), $k = 13$, $n = 4824$] and random-effects models [$r = 0.24$, 95% CI (0.19, 0.29), $k = 13$, $n = 4824$]. The variability across samples was significant ($Q = 23.77$, $df = 12$, $p = 0.02$) and moderate as the I^2 indicated that 49.51% of the observed variability was beyond what would be expected by chance.

Measure of nature connectedness

The relationship between nature connectedness and happiness may depend on the measure used to assess one's connection to nature. Because some of the samples used multiple measures of nature connectedness, conducting moderator analyses on this variable would violate the principle of independence. For this reason, general patterns were observed by conducting separate meta-analyses for the three most commonly used measures of nature connectedness: the connectedness to nature scale (Mayer and Frantz, 2004), the inclusion of nature in self-scale (Schultz, 2001), and the nature relatedness scale (Nisbet et al., 2009).

Table 5 | Fixed-effect between-level Q moderator analysis for publication bias.

	r	95% CI	Q	I^2 (%)	k	n	Samples Included
Overall	0.19	[0.16, 0.21]	64.29***	54.89	30	8523	All
Unpublished	0.19	[0.15, 0.22]	28.84**	61.85	12	4561	1, 2a, 2b, 8, 9, 10, 11, 12, 13, 15, 16, 19
Published	0.19	[0.16, 0.22]	35.44**	52.03	18	3962	3.1, 3.2, 3.5, 4.1, 4.2, 5.1, 5.2, 6, 7.4, 14.1, 14.2, 17.4, 18.1, 20.1, 20.2, 21.1a, 21.1b, 21.2
$Q_{between}$			0.01				

**$p < 0.01$; ***$p < 0.001$.

Samples that did not contain a particular type of nature connectedness measure were excluded from that respective meta-analysis and overall effect sizes for each were calculated for the remaining samples. Both fixed-effect and random-effects meta-analyses were conducted.

Connectedness to nature. A small mean weighted effect size was found between happiness and connectedness to nature in the fixed-effect [$r = 0.18$, 95% CI (0.14, 0.22), $k = 13$, $n = 2615$] and random-effects models ($r = 0.18$, 95% CI (0.13, 0.24), $k = 13$, $n = 2615$]. The variability across samples was significant ($Q = 23.80$, $df = 12$, $p = 0.02$) and moderate as the I^2 indicated that 49.59% of the observed variability was beyond what would be expected by chance.

Inclusion of nature in self. A small mean weighted effect size was found between happiness and inclusion of nature in self in the fixed-effect [$r = 0.27$, 95% CI (0.23, 0.32), $k = 6$, $n = 1671$] and random-effects models [$r = 0.25$, 95% CI (0.15, 0.35), $k = 6$, $n = 1671$]. The variability across samples was significant ($Q = 21.59$, $df = 5$, $p < 0.001$) and high as the I^2 indicated that 76.84% of the observed variability was beyond what would be expected by chance.

Nature relatedness. A small mean weighted effect size was found between happiness and nature relatedness in the fixed-effect [$r = 0.18$, 95% CI (0.16, 0.21), $k = 17$, $n = 6255$] and random-effects models [$r = 0.18$, 95% CI (0.14, 0.22), $k = 17$, $n = 6255$]. The variability across samples was significant ($Q = 28.63$, $df = 16$, $p = 0.03$) and moderate as the I^2 indicated that 44.12% of the observed variability was beyond what would be expected by chance.

DISCUSSION

The purpose of this study was to provide a quantitative summary of the literature on the link between nature connectedness and happiness. Auspiciously, a fairly clear picture emerged. The relationship between nature connectedness and happiness appears to be positive and significant. In general, individuals who are more connected to nature tend to be happier.

Demographic characteristics, such as gender and age, did not moderate this relationship despite previous research finding that being older and female tends to be associated with increased pro-environmental concern, attitudes, and behaviors (e.g., Grønhøj and Thøgersen, 2009; Scannell and Gifford, 2013). It appears that possible age or gender differences in nature connectedness or well-being did not impact the association between the two. Publication bias did not appear to be an issue, nor was any evidence for the decline effect found—thus increasing confidence in the current meta-analytic summary effect.

How happiness was defined and measured did appear to have an influence on the magnitude of the effect size, with vitality being the most strongly associated with nature connectedness, followed by positive affect and life satisfaction. Nature's restorative effects might explain why vitality has the strongest relationship with nature connectedness (Kaplan, 1995). Beyond its ability to improve emotional functioning, exposure to natural environments has also been shown to alleviate cognitive fatigue, improve attention, and increase feelings of vitality (Berman et al., 2008; Ryan et al., 2010; Nisbet et al., 2011). As those who are higher in nature connectedness are more likely to spend time in nature, they may be beneficiaries of both the affective and revitalizing effects of natural environments, which is reflected by nature connectedness' even stronger association with vitality compared to the other measures of happiness. Vitality being a traditionally eudaimonic measure of well-being might also explain its higher mean weighted effect size. Increased concern for the environment and engagement in sustainable behaviors might carry more hedonic than eudaimonic costs to well-being (Venhoeven et al., 2013) and this may manifest in slightly lower correlations with the more classically hedonic measures of well-being (i.e., positive affect and life satisfaction). The variability in mean weighted effect sizes may be partially due to vitality and positive affect being affective components of well-being, while life satisfaction is more of a cognitive component (Diener and Lucas, 1999; Diener, 2009). Although the different measures of subjective well-being are typically conceived of as assessing the same underlying construct and factor analysis supports this (Sandvik et al., 1993), correlations between different measures of subjective well-being (e.g., recalled positive affect and life satisfaction) tend to be moderate in magnitude (Lucas et al., 1996) indicating that the constructs are not identical (Kim-Prieto et al., 2005). The non-shared variance between measures of subjective well-being might partly explain some of the varying results. Lastly, different proportions of the nature connectedness measures included within each of the meta-analyses could have conceivably influenced or confounded the results. This is unlikely as the percentages of nature connectedness measures within each type of happiness meta-analysis remained fairly consistent, with nature relatedness being the most common (ranging from being in 69.2% of the samples in the vitality meta-analysis to 68.4% of the samples in the positive affect meta-analysis), followed by inclusion of nature in self (ranging from being in 31.3% of the samples in the life satisfaction meta-analysis to 21.1% of the samples in the positive affect meta-analysis), and connectedness to nature (ranging from being in 30.8% of the samples in the vitality meta-analysis to 25% of the samples in the life satisfaction meta-analysis) Regardless of all these explanations, the effect size from each of the meta-analyses examining type of happiness remained relatively similar in magnitude (i.e., small) and all of the fixed-effect confidence intervals either almost overlapped (i.e., vitality and life satisfaction) or did overlap (i.e., vitality and positive affect, as well as positive affect and life satisfaction).

How nature connectedness was defined and measured also appeared to have an influence on the magnitude of the effect size, with inclusion of nature in self-having a particularly stronger relationship with happiness compared to nature relatedness and nature connectedness. This is consistent with the pattern of results found in Zelenski and Nisbet (2014) where zero-order correlations between measures of happiness and nature connectedness were larger for inclusion of nature in self than nature relatedness. One possible explanation for this difference is that inclusion of nature in self may also assess general connectedness more than other measures of nature connectedness which might more precisely tap individuals' subjective connection to nature (Zelenski and Nisbet, 2014). Considering the aforementioned well-being benefits associated with social connection (Ryan and Deci, 2001), more overlap between the general construct of connectedness and inclusion of nature in self could increase the latter's relationship with happiness. In fact, inclusion of nature in self, compared to nature relatedness, has been found to correlate substantially more with general connectedness (Zelenski and Nisbet, 2014). In contrast to these patterns of results, Tam (2013a) found that inclusion of nature in self consistently shared the weakest association with subjective well-being out of all the nature connectedness measures. As Tam (2013a) was the one study on this topic that was conducted in Asia, cross-cultural differences may account for these inconsistencies. Related to this point, researchers in this area should attempt to recruit participants from more diverse backgrounds beyond western, educated, industrialized, rich, and democratic societies (Henrich et al., 2010), as the majority of samples in this meta-analysis came from Canada and the USA. This is especially pertinent given the cultural differences that have been observed in how people conceptualize the relationship between humans and nature (e.g., Bang et al., 2007; Unsworth et al., 2012). The differential distribution of happiness measures is an unlikely explanation for the varying effect sizes found in the separate nature connectedness meta-analyses as the majority of overall/averaged effect sizes within each were based on mixed measures of positive affect, vitality, and/or life satisfaction. Regardless of these explanations, the confidence intervals either almost overlapped (i.e., in the fixed-effect meta-analyses) or did overlap (i.e., in the random-effects meta-analyses). It should also be noted that the number of samples was fairly low ($k = 6$) and the variability between samples was high in the inclusion of nature in self meta-analysis.

Although the overall effect size from this meta-analysis can be considered small when one follows conventions (Cohen, 1988), as was first noted by Mayer and Frantz (2004), it is similar in size to other variables widely thought to have a positive relationship with happiness, such as personal income within countries (Haring et al., 1984; Diener et al., 1993), education (Witter et al., 1984; Diener et al., 1993), religiosity (Witter et al., 1985; Hackney and Sanders, 2003; Diener et al., 2011), marital status (Haring-Hidore et al., 1985; Diener et al., 2000), volunteering (Thoits and Hewitt, 2001), and physical attractiveness (Diener et al., 1995; Plaut et al., 2009). Furthermore, it is similar in magnitude to the association between subjective well-being and some personality traits such as conscientiousness and agreeableness (DeNeve and Cooper, 1998; Steel et al., 2008). More generally, the overall effect size between nature connectedness and happiness is similar to the average result found in social psychology (i.e., $r = 0.21$; Richard et al., 2003). Thus, a person's connection to nature should be considered an important construct when discussing happiness and vice versa.

It should be noted that correlation does not equal causation. Higher nature connectedness may cause increased happiness, higher happiness may cause increased nature connectedness, or a third variable might be leading to changes in both variables. Studies have been conducted that employ experimental designs and attempt to manipulate nature connectedness and/or happiness (e.g., Nisbet, 2011). Using statistical mediation analyses, some studies have found that exposure to nature increases nature connectedness because it promotes positive affect (Nisbet and Zelenski, 2011), while other studies have found that nature exposure increases people's emotional well-being partially due to increased nature connectedness (Mayer et al., 2009). Due to the problems associated with meditation analyses (see Bullock et al., 2010) and the fact that these studies confound nature exposure and positive emotions, future research is needed to determine the directionality of this relationship. To our knowledge, no studies have experimentally manipulated happiness (without nature) to examine whether it would lead to a greater sense of connection to the natural world, above and beyond other subjective connections (cf. Zelenski and Nisbet, 2014). This could offer a valuable extension to Fredrickson's (2004) broaden-and-build theory of positive emotions beyond social bonds to connections with nature as well.

Strong subjective connections to nature may begin in childhood. However, the association between childhood experiences and an individual's level of nature connectedness as an adult has only been established through recall in self-reports (Tam, 2013a) thus far. Conducting longitudinal studies that follow individuals across the lifespan would allow researchers to more accurately answer whether childhood contact with nature predicts nature connectedness years later. This could test Orr's (1993) idea of a critical period for developing biophilia and could help explain individual differences in people's subjective connection to nature. The relationship that nature connectedness has with negative emotional functioning, physical health, and cognitive abilities are also promising areas of investigation (cf. Bowler et al., 2010).

Although vitality was included in the operational definition of happiness in this paper, an examination of the relationship between nature connectedness and other constructs that are commonly thought of as eudaimonic well-being such as autonomy, personal growth, self-acceptance, purpose in life, environmental mastery, and positive relations (Ryff, 1989), would provide a fruitful avenue for future research and meta-analysis in and of itself. Of the fewer studies that have looked at this relationship, they tend to find a positive association between nature connectedness and measures of eudaimonic well-being as well (Howell et al., 2011, 2013; Nisbet et al., 2011; Zelenski and Nisbet, 2014). It would be interesting to examine whether this relationship differs significantly in strength from the association found between nature connectedness and hedonic well-being. A review of how pro-environmental behaviors can influence well-being in both positive and negatives ways by Venhoeven et al. (2013) hints that it might as research "suggests that engaging in pro-environmental behavior may have especially negative consequences for hedonic well-being, but mainly positive consequences for eudaimonic well-being" (p. 1380). Although there are circumstances where this may not hold true, the eudaimonic motive of "doing something good" like engaging in pro-environmental behaviors, even when it is difficult, costly, or time-consuming, logically may lead to eudaimonic but not hedonic well-being. As nature connectedness predicts sustainable attitudes and behaviors (Mayer and Frantz, 2004; Leary et al., 2008; Nisbet et al., 2009; Tam, 2013a), this suggests that the relationship between nature connectedness and eudaimonic well-being may be even stronger. That nature connectedness was most strongly associated with vitality also seems to offer preliminary support for this prediction.

Nevertheless, this meta-analysis provides results that run somewhat counter to what one would predict based on Venhoeven's (2013) review as subjective connection to nature is associated with greater hedonic well-being, not less. This suggests that although some aspects of the human-nature relationship have the potential to detract from our happiness (e.g., some pro-environmental behaviors), other aspects may compensate and result in a net increase (e.g., a subjective connection to and contact with nature). Instead of potentially difficult, time-consuming, and costly pro-environmental behaviors coming at an expense to our subjective well-being, sustainable behaviors might be a pleasant expression of a trait (i.e., nature connectedness) that promotes overall positive emotional functioning. This has important implications as we attempt find solutions to many of the problems we face in the twenty-first century, such as climate change and the rising burden of disease of mental illness (World Health Organization, 2001).

Similar to how all the different conceptualizations of well-being were not included in this meta-analysis, other constructs relating to the human-nature relationship (e.g., dispositional empathy with nature; Tam, 2013b) may have been overlooked that warrant further investigation. Moreover, opportunities to develop novel constructs beyond nature connectedness could be expanded by applying existing psychological theories and concepts about human interpersonal relations to the human-nature domain (Tam, 2014). For instance, attachment theory could be extended to a person's attachment to nature, with different attachment styles (i.e., secure, anxious-preoccupied, dismissive-avoidant, and fearful-avoidant; Bartholomew and Horowitz, 1991) potentially being assessed and used to predict variables like connection to nature, environmental attitudes, and likelihood of engaging in sustainable behaviors.

Despite the unambiguous findings of the current meta-analysis and the preferences for nature that people commonly hold (Frumkin, 2001), research suggests that individuals tend to commit affective forecasting errors and underestimate the hedonic benefits that being in nature will bring them (Nisbet and Zelenski, 2011). Given that people are spending the vast majority of their time indoors (Evans and McCoy, 1998; MacKerron and Mourato, 2013) and the increasing urbanization of the world's population (United Nations Population Division, 2002), many of us may be missing out on the beneficial effects of connecting to nature in the moment and in general. This could be contributing to a decrease in not only our own well-being, but that of our planet as well. The current meta-analysis provides further evidence that a sustainable future and a happy future are compatible and symbiotic, not mutually exclusive.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.00976/abstract

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Does awareness effect the restorative function and perception of street trees?

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Urban streetscapes are outdoor areas in which the general public can appreciate green landscapes and engage in outdoor activities along the street. This study tested the extent to which the degree of awareness of urban street trees impacts attention restoration and perceived restorativeness. We manipulated the degree of awareness of street trees. Participants were placed into four groups and shown different images: (a) streetscapes with absolutely no trees; (b) streetscapes with flashes of trees in which participants had minimal awareness of the content; (c) streetscapes with trees; and (d) streetscapes with trees to which participants were told to pay attention. We compared the performance of 138 individuals on measures of attention and their evaluations of perceived restorativeness. Two main findings emerged. First, streetscapes with trees improved the performance of participants on attentional tests even without their awareness of the trees. Second, participants who had raised awareness of street trees performed best on the attentional test and rated the streetscapes as being more restorative. These findings enhance our knowledge about the role of an individual's awareness of restorative elements and have implications for designers and individuals who are at risk of attentional fatigue.

Keywords: DSBT, attention restoration, perceived restorativeness, manipulation on awareness degree

"心不在焉，視而不見，聽而不聞，食而不知其味。"
《禮記•大學》

"*When one is absent-minded, he looks but sees nothing, hears but pays no attention, and eats but has no taste for it.*"
(The Great Learning, Classic of Rites)

INTRODUCTION

Elements in the natural environment improve psychological well-being by reducing stress, restoring attention, and increasing positive emotions and esthetic values (Ulrich, 1984; Ulrich et al., 1991; Korpela et al., 2002; Groenewegen et al., 2006; Abraham et al., 2010; Bowler et al., 2010; Kaplan and Kaplan, 2011). Studies have demonstrated that increasing natural elements in an urban environment improved individuals' well-being (Kaplan, 2007; Chang et al., 2008; Korpela et al., 2010; Martens et al., 2011). In particular, natural elements in urban landscapes can help people pay attention or restore their capacity to pay attention. Kaplan and Kaplan's Attention Restoration Theory (ART) proposes that individuals' directed attention has limited capacity which becomes depleted when processing non-fascinating information about one's environment or performing attentionally demanding tasks (Kaplan and Kaplan, 1989).

Because directed attention is also needed for executive functioning and self-regulation (Korpela et al., 2001; Kaplan and Berman, 2010), directed attention fatigue can lead to a variety of negative consequences such as inability to concentrate, irritability, and even violent behavior (Kuo and Sullivan, 2001; Taylor and Kuo, 2009). Exposure to natural environments and to built environments that include natural elements such as trees have been shown to enhance an individuals' ability to recover from directed attention fatigue (Herzog et al., 2003; Laumann et al., 2003; Berto, 2005; Berman et al., 2008; Staats et al., 2010). Thus, understanding nature's ability to restore directed attention is useful in preventing the negative consequences of directed attention fatigue.

Do natural environments benefit individuals even when they are not aware of their surroundings? Kaplan (2001) argued that these restorative effects could happen without awareness. However, some studies used ART as a theoretical framework to discuss restorative environmental characteristics via self-rating questionnaires (e.g., Hartig et al., 1997, 2003; Chang et al., 2008), which requires participants to think back on their experience, hinting that restorative outcomes require awareness. Therefore, these studies implicitly assume positive environmental characteristics were consciously, not subconsciously, noticed by people. In one study, self-rated restorativeness was correlated with directed attention restoration (Berto, 2005). In spite of these associations, few previous studies have manipulated levels of awareness of natural elements and then examined the resulting impacts on attentional functioning. By manipulating people's awareness of natural elements, this study helps fill a gap in our knowledge regarding the extent to which awareness of natural elements in the landscape enhances one's restorative experience.

Our research is focused on urban streetscapes because the general public encounters urban streetscapes frequently. Few previous findings regarding the restorative effects of natural elements, such as trees, have specifically focused on urban streetscapes. Therefore, we raise two research questions: Will adding natural elements (e.g., trees) into a streetscape enhance restorative effects? Will the effects differ depending on the level of awareness that participants have of the natural elements? By answering these questions we hope to better understand the role of awareness in the restorative effect of nature. Our findings will have implications for educators, health care providers, designers, and urban planners who want to enhance the restorative effects of urban landscapes.

RESTORATIVE EFFECTS OF NATURE IN URBAN ENVIRONMENTS

Kaplan's (1995, 2001) ART proposes that 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" (Berman et al., 2008). Directed attention fatigue can be relieved in a green setting because such places are often softly fascinating and thus allow a person to give their directed attention a rest (Herzog et al., 1997; Berto et al., 2008). An extensive body of empirical evidence has accumulated in support of ART. The findings come from very green settings such as large and small forests (Park et al., 2010; Shin et al., 2010), rural areas (Roe and Aspinall, 2011), wilderness settings (Hartig et al., 1991), and prairies (Miles et al., 1998). But the same is true for more modestly green settings such as community parks (Hartig et al., 2003; Krenichyn, 2006; Fuller et al., 2007; Korpela et al., 2008), schools (Matsuoka, 2010), and neighborhoods (Tennessen and Cimprich, 1995; Wells, 2000; Kuo and Sullivan, 2001; Taylor et al., 2002; Rappe and Kivelä, 2005).

ART identifies four characteristics of physical settings that contribute to restorative experiences. The first characteristic is *fascination*, the first proposed and necessary component of a restorative setting, describes objects or places that require little or no attentional effort—that is, little or no directed attention. A gentle form a fascination, what Kaplan and Kaplan (1989) call soft fascination (e.g., watching a waterfall, leaves moving in a breeze, fish in a pond), holds your involuntary attention in such a way as to leave some capacity to examine some of the thoughts that have been running around in your head. Softly fascinating settings foster restorative experiences (Kaplan et al., 1998; Herzog et al., 2011).

Being away (Kaplan and Kaplan, 1989) involves eliminating distractions from your surroundings, taking a break from your usual work or responsibilities, and ceasing pursuit of attentionally demanding tasks or activities. You might experience a feeling of being away if you stayed all day in an elevator. But doing so would by unlikely to produce a restorative experience. The Kaplans suggest that a sense of extent might also help.

Extent, the third proposed component of a restorative setting, describes a place that is "rich enough and coherent enough so that it constitutes a whole other world" (Kaplan, 1995, p. 173). "In a coherent environment, things follow each other in a relatively sensible, predictable, and orderly way" (Kaplan, 2001, p. 488). Extent is also aided by a setting that has sufficient scope. The key with respect to scope is that the setting be either physically large enough or conceptually large enough that one's mind can wonder within it. This process of allowing your thoughts to drift away from your daily activities into something that is rich and non-threatening seems an important part of a restorative experience. In this study, we examine the extent in terms of the level of coherence and scope available in various streetscapes.

Compatibility is the final proposed component of a restorative setting. Compatibility refers to the extent to which an environment supports your inclinations and purposes. It involves the fit between what you are trying to accomplish in the moment and the kind of activities supported, encouraged, or demanded by the setting (Herzog et al., 2003). Some settings will work against one's inclinations, others will meet some of them, and still others will be supportive in most every way. Settings that contain natural elements are often compatible with the kind of activities that lead to restoration.

Several studies have used these four environmental characteristics to measure a landscape's restorative qualities (Hartig et al., 1997; Laumann et al., 2001; Herzog et al., 2003; Berto, 2005). In this study, we also ask participants to evaluate the landscapes according to these characteristics of restorative landscapes.

DOES THE DEGREE OF AWARENESS INFLUENCE THESE RESTORATION?

The role of awareness in understanding the impacts of green spaces on restoration is unclear. In previous studies, the role of voluntary attention and involuntary attention, directed attention and fascination, and selective attention have been examined. Little research, however, has examined the extent to which paying attention to landscape features impacts attentional restoration. Some finding suggests that an environment can affect perceptions without awareness. For example, when it comes to people-environment relationships, the interaction is assumed to be a preconscious process (Parsons and Daniel, 2002). However, Kaplan (2001) suggested that paying attention to landscape characteristics might lead to enhanced restoration. The effect of participants' awareness of landscape features on restorative outcomes has yet to be tested and clarified.

During the process of visual perception, visual attention and awareness are inseparable. When individuals receive visual information, their visual attention focuses on specific bits of information and inhibits their awareness of other information. Visual awareness extracts the targeted information and sends it to the brain for further interpretation (Goldstein, 2007, p. 5).

Can different levels of visual awareness be observed and manipulated in experiments? Yes, research demonstrates that awareness levels can be manipulated (Tang and Posner, 2009). Subliminal visual attention, in which participants see something for such a short time that they are not fully aware of it, can be simulated in a laboratory setting (Erdelyi, 2004). People who were shown rapid images of snakes and spiders had the same level of fear as individuals who were shown the same images for longer periods of time. This suggests that attentional response can be activated very rapidly and without heightened awareness, requiring only minimal stimulus input (Globisch et al., 1999).

Visual awareness can be heightened when participants are instructed to carefully investigate a setting (Leff et al., 1974; Duvall, 2011). Works by Duvall (2011, 2012, 2013), for example, showed that instructions provided in a walking activity could alter perceptions and satisfaction of the environment and hence change the walking behavior. This suggests that awareness of the vegetation in a setting, in contrast to visual attention, could be heightened through instructions. If the awareness of the vegetation is strategically heightened, individuals may experience the landscape differently and report enhanced psychological well-being.

Although ART proposes that viewing natural elements such as trees, water, and flowers can restore directed attention, exposure to specific features in a setting and the awareness of those features have not been examined. We are therefore curious about the extent to which awareness levels influence attention restoration and the evaluation of the restorative characteristics of a setting—being away, fascination, extent (including scope and coherence), and compatibility. In sum, we ask two questions: To what extent is the greenery of an urban street beneficial to the attention-restoration experience? Will the degree of awareness of the streetscape's green features impact directed attention restoration and people's evaluation of an environment's restorativeness?

METHOD

The objective of this study is to investigate whether directed attention and the evaluation of a streetscape's restorative characteristics would be affected by different degrees of awareness. To achieve this goal, we exposed 138 participants to four different conditions: 1. Urban streetscapes with no greenery, 2. Urban streetscapes with brief flashes of greenery (enough to direct attention but not awareness), 3. Urban streetscapes with greenery presented the entire time, and 4. Urban streetscapes with the same greenery as in the third manipulation but with added instructions to pay attention to the greenery. Participants were randomly assigned to view one of the four conditions and were asked to rate the four restorative characteristics and complete tests to measure how their directed attention capability recovered.

PARTICIPANTS

A total of 140 undergraduate students from National Taiwan University (NTU) participated in this study. After eliminating two survey questionnaires with outlier total scores, the final sample is 138, consisting of 73 females and 65 males. The experiments were carried out between May and June in 2012 in classroom contexts in the Department of Horticulture and Landscape Architecture at NTU. The purpose of the study was explained at the beginning and the students were free to leave or to participate. The students who volunteered to participate received no compensation or credit for their participation.

STIMULUS MATERIALS

To create the streetscapes, we took photographs of mixed residential-commercial areas with buildings between four and six-stories tall. Photographic images of five streetscapes without greenery in Taipei City were taken, which were used as the stimulants in the No Trees group. These images were taken at a height of 1.5 meters. Next, we used Adobe Photoshop CS 3.0 to edit the images to simulate streetscapes with 30–40% greenery along the sidewalks (**Figure 1**). The streetscapes with trees were used as the stimulants for the three groups with the same amount of greenery but different levels of awareness.

TREATMENT CONDITIONS

Following the between-subject design, participants were randomly assigned to one of four groups with differing greenery images and awareness levels: (a) The No Trees group was shown streetscape images with no greenery. The awareness level for this group was none. (b) The Minimal Awareness group was shown the same images but mixed with rapid flashes of simulated

FIGURE 1 | Streetscape images. (Upper row, streetscape with no greenery; Lower row, streetscape with simulated greenery).

greenery a few times. Participants could notice the trees flashing in and out, but were not substantially aware of the greenery. (c) The Moderate Awareness group was shown the images with simulated greenery for the entire time rather than in brief flashes. The awareness level for this group is moderate. (d) The Heightened Awareness group was shown the same greenery images as the previous two groups but was also given verbal instruction to observe the greenery carefully. Therefore, their awareness of the greenery was heightened.

Streetscapes for each group consisted of five images. Each image was shown for 20 s (100 s in total). Prior to seeing these streetscape images, there was a slide with these instructions: "*Now a number of images of streetscapes will be shown. Please relax and imagine being in the settings. You will be asked to answer some questions about the environments after watching these images. Please observe them closely.*" In the Heightened Awareness group, this last sentences was changed to "Please observe the plants closely." The No Tree participants saw five images of the streetscape without greenery. For the Minimal Awareness group, while the participants were watching the original streetscape images, flashes of images containing greenery appeared every 5 s. Each flash was composed of three images: (a) a horizontally flipped image of the same streetscape image (mask), (b) a streetscape image with added greenery, and (c) a horizontally flipped image of the same streetscape image (mask) (see **Figure 2**). These three images appeared for 0.03 s each. The participants in this group saw these flashes of images without seeing actual content of trees. For the Moderate Awareness group, participants saw the images of the streetscapes with greenery present the entire time. The Heightened Awareness participants saw the images of the streetscapes with greenery and received these instructions: "*Now a number of images with plants will be shown. Please relax and imagine being in these settings. You will be asked to answer some questions about the plants after watching these images. Please observe the plants closely.*"

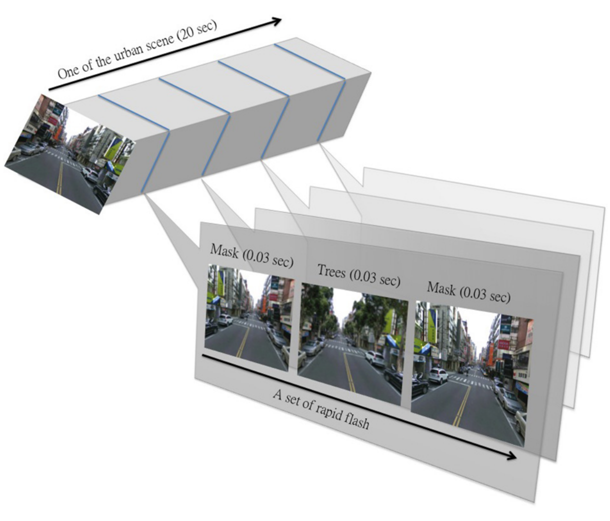

FIGURE 2 | How the rapid flashed of street trees were flashed in. (Note: A mask is the horizontally flipped image of the streetscape being played).

PROCEDURE

The experiments were scheduled with students in one of several classrooms directly following the class. Participants had just finished a class and were in a slightly fatigued state. We explained the purpose of the experiment, which was to understand how viewing a landscape would affect their responses and feelings. We then explained the experimental procedure to the participants. Next, we showed an example image (also from the street in Taipei, but not the image used in the stimulus material) to ensure that every participant could see the screen clearly. Then, participants engaged in a Digit Span Backward Test (DSBT), to evaluate their level of directed attention. The procedure for this test is described in Section Attention task.

The experiment started with the DSBT pre-test, after which the participants were shown five sets of images of streetscapes. Participants were then asked to answer five Perceived Restorativeness Scale (PRS) questions, and then underwent the DSBT post-test. The DSBT prompt and the images of the streetscapes were presented on a screen with PowerPoint 2007. At the end of these tests, participants answered demographic questions and were then asked to identify the species of the plants they had just seen (open-ended questions). The full procedure took 25–30 min to complete.

MEASUREMENTS

Attention task

This study employed the DSBT to measure directed attention before and after watching the stimulus so we were able to determine changes in attentional functioning. In the DSBT test, participants must exercise their short-term memory, holding in memory—then repeating in reverse order—a string of numbers. Prior to the test, we gave participants the following instructions: "You will see some numbers appear on the screen, each number will appear for 1 s and then another number will appear. Read the numbers carefully. After the numbers have been presented, write them down in reverse order. The task will last for 14 trials. You can stop whenever you can't remember the sequence." We began with a practice trial after which participants were allowed to ask questions. After we addressed any questions, the real trials began. Each trial began with a cross in the middle of the screen and ended with a word "answer." Only when the instructor confirmed the participant has looked back to the screen then did the next trial begin. The length of the set of numbers gradually increased from 4 to 10 digits; two sets of numbers were presented at each length, such that there were two sets of four digits, two at five digits and so fourth for a total of 14 trials. The length of digits repeated correctly just prior to the first mistake the participant made was used as the test score (a minimum score of 4 and a maximum score of 10).

Perceived restorativeness

Based on ART's characteristics of a restorative environments, participants rated five environmental characteristics (i.e., being away, fascination, coherence, scope, and compatibility) on a seven-point scale (0 = strongly disagree, 3 = neither agree or disagree, 6 = strongly agree) which was translated from Berto's 5-item version of PRS (Berto, 2005). Translated Mandarin version of the

5-item statements is presented in the Appendix. These five items were:

- 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);
- That place is fascinating; it is large enough for me to discover and be curious about things (fascination);
- That is a place where the activities and the items are ordered and organized (coherence);
- That is a place that is very large, with no restrictions to movements; it is a world of its own (scope);
- In that place, it is easy to orient and move around so that I could do what I like (compatibility).

Reported plant species

The final item in the questionnaire asked participants to identify the different plant species they had seen. For a manipulation check, this question is expected to test how much participants were aware of the greenery, depending on their awareness group. We hypothesized that the greater the awareness level, the greater the number of reported plant species.

RESULTS

MANIPULATION CHECK—REPORTED PLANT SPECIES

Were we able to successfully manipulate the level of awareness for the different groups? In order to verify the effects of the awareness level manipulation, we examined the difference between the reported numbers of plant species. Results showed significant differences between the reported number of plant species by the four groups [$F_{(3)} = 47.64$, $p \leqq 0.001$]. Through Scheffe's *post-hoc* analysis we confirmed that there is no difference between the reported number of plant species between the No Tree group, the group exposed to urban cityscapes with no trees (mean = 0.06; $SD = 0.24$), and the Minimal Awareness group, the group shown brief flashes of trees (mean = 0.03; $SD = 0.18$). The reported number of plant species by the Moderate Awareness group, the group shown constant images of cityscapes with trees (mean = 1.25; $SD = 0.73$) is greater than that by No Tree and Minimal Awareness groups. The number of species reported by the Heightened Awareness group, the group shown images of streetscapes with trees and given verbal instruction to pay close attention to the greenery (mean = 1.84; $SD = 1.26$), is greater than all other groups (**Figure 3**). These outcomes confirmed that the manipulation of awareness level for the groups produced the expected effects.

GREENERY AND DIRECTED ATTENTION RECOVERY

To ensure that there is no difference between the cognitive competencies of the test subjects in the four different groups, we used ANOVA to test the pre-test scores of DSBT, the attentional test. The result showed that there is no difference of the subjects from the four groups [$F_{(3)} = 1.97$, n.s.].

In order to confirm that looking at landscape photos (the treatment in the experiment) effects participants' ability to focus their attention, we conducted a paired t-test on the pre-test and post-test scores of the DSBT. Results demonstrated that there are significant differences between the pre-test and post-test scores of all the four groups (**Table 1**), which indicates that the treatments employed generated the expected outcomes. The post-test scores achieved by the No Tree group are noticeably lower than the scores on their pre-test. In other words, the directed attention of these participants did not recover during the process of looking at the photos; rather, it diminished. On the other hand, the post-test scores achieved by the other three groups (i.e., Minimal Awareness, Moderate Awareness, and Heightened Awareness) are all significantly greater than their respective pre-test scores. That is, the appearance of greenery, regardless of whether the participant was aware of the shape and type of the plant, has restorative effects on directed attention fatigue (**Table 1**).

AWARENESS AND DIRECTED ATTENTION RECOVERY

In order to identify whether the degree of awareness of streetscape greenery affects the recovery of directed attention, the next step is to test for differences across these four groups. We first calculated the difference between pre-test and post-test scores of the DSBT, the directed attention test (**Table 2**); next, we employed ANCOVA to examine the differences between the test scores of the four groups. The results showed that awareness level does have an effect beyond and above the attention recovery level (difference between DSBT pre-test and post-test) even after we controlled the participant's baseline (pre-test), where

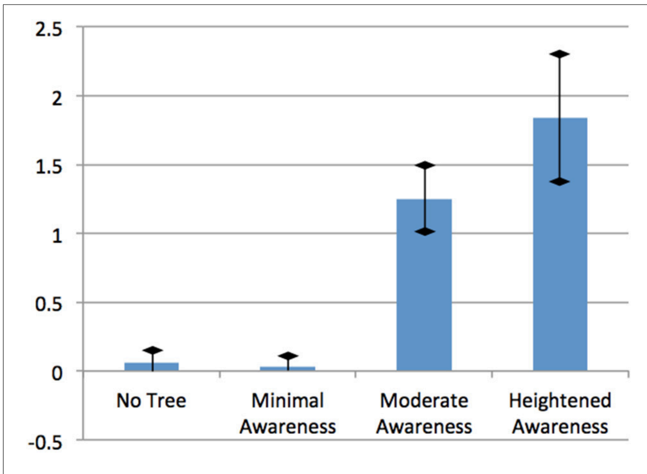

FIGURE 3 | The reported number of plant species by each group. The error bars show a 95% confidence interval.

Table 1 | Mean directed attention score before and after treatment.

Group	DSBT pre-test	DSPT post-test	*T*
No tree ($n = 34$)	7.12 (1.45)	6.53 (1.38)	2.385*
Minimal Awareness ($n = 31$)	6.45 (1.55)	7.06 (1.44)	−2.31*
Moderate Awareness ($n = 36$)	6.28 (1.50)	6.83 (1.44)	−2.28*
Heightened Awareness ($n = 37$)	6.57 (1.56)	8.05 (1.53)	−5.68**

Standard deviations are in the parentheses.
*Note: *p ≦ 0.05, **p ≦ 0.001.*

$F_{(3,\ 133)} = 11.84$, $p < 0.001$. Paired comparison showed that the attention recovery score achieved by the Heightened Awareness treatment is significantly greater than that achieved by all the other groups. There is no difference between the Moderate Awareness and the Minimal Awareness treatments, and both scores are higher than that achieved by the No Tree treatment.

AWARENESS AND PERCEIVED RESTORATIVENESS

To what extend did awareness of greenery influence participants' assessments of how restorative the street scenes were? To examine this question, we tested the groups' scores for the PRS. Results showed a significant difference between the total PRS scores (**Table 2**). The Heightened Awareness group rated the scenes as significantly more restorative than the No Tree group. However there was no other difference between groups. This outcome implies that the awareness enhancing strategies may play a role in perceiving or appreciating restorativeness of urban greenery (see **Table 2**).

Next, we focused on the characteristics evaluated in the PRS questions separately in order to see how levels of awareness influenced evaluation of each characteristic. As can be seen in **Table 2**, there are significant differences among the groups for "being away" and "coherence." There is also a marginal difference among the groups for "scope." Scheffe *post-hoc* analyses showed that the Heightened Awareness group rated the landscape characteristics "coherence" higher and "scope" marginally higher than No Trees group. The "being away" characteristic is not different among the groups. There is no other difference among the groups. These findings suggest that heightened awareness made participants more likely to notice and appreciate the sense of coherence and scope in the streetscapes.

DISCUSSION

This study examined the extent to which raising awareness about trees in a streetscape could impact a person's capacity to pay attention and their evaluation of the restorativeness of a setting. The results revealed that increasing awareness had systematically significant impacts on participant's scores assessing their capacity to direct their attention. The findings provide new information about the benefits of green infrastructure on an individual's capacity to pay attention, shed new light on the role of awareness of one's surroundings, and raise questions for future research.

BENEFITS OF URBAN STREET TREES ON ATTENTION

The results confirmed previous research demonstrating that views of trees have positive impacts on adult's capacity to pay attention. We measured the attention performance with the DSBT before and after treatment for all four groups. As expected, all three groups that had views of street trees, regardless of the level of awareness that participants had of the trees, improved their directed attention. Only the group that viewed street scenes without trees had a measurable decrease in attentional functioning.

This contrasting result of decreased attention performance shown by the group looking at images of street scenes without trees demonstrated that built environments without vegetation did not possess restorative characteristics and might in fact drain existing reserves of attention. This finding is similar to the concept proposed by Parsons et al. (1998) that built elements do not produce positive effects on stress recovery and may lead to negative effects. Our findings are consistent with a study in which participants walked in an urban commercial district and in an arboretum. The authors of that study found that urban settings require people to constantly use directed attention to overcome the stimulants in their environments (Berman et al., 2008).

EFFECT OF AWARENESS ON ATTENTION AND PERCEIVED RESTORATIVENESS

The findings of this study confirmed the hypothesis that raising awareness of trees improved directed attention recovery and perceived restorativeness.

In terms of directed attention, our results demonstrated that even individuals who had minimal awareness of the trees (those who saw the trees as quick flashes) improved their scores on the test of direct attention. In other words, the appearance of natural content can produce restorative effects for attention restoration without awareness. Still, the participants who were instructed to purposely observe the trees performed even better on the

Table 2 | Cognitive performance of the four test groups.

	No tree	Minimal awareness	Moderate awareness	Heightened awareness	*F*
DSBT[a]	−0.59[+◈] (1.44)	0.61[+‖] (1.48)	0.56[+‖] (1.46)	1.49[◈‖] (1.59)	11.84***
PRS[b]	13.59[+] (4.05)	14.90 (3.70)	15.31 (4.41)	16.81[‖] (5.86)	2.92*
Being away	2.32 (1.07)	2.29 (0.94)	2.83 (1.38)	3.03 (1.34)	3.21*
Fascination	2.82 (1.29)	3.10 (1.08)	2.97 (1.21)	3.14 (1.32)	0.45
Coherence	2.97[+] (1.24)	3.52 (1.15)	3.61 (1.15)	4.05[‖] (1.33)	4.66**
Scope	2.35[+] (1.04)	2.84 (1.29)	2.78 (1.07)	3.14[‖] (1.55)	2.31+
Compatibility	3.12 (1.27)	3.16 (1.21)	3.11 (1.43)	3.46 (1.56)	0.52

Standard deviation in parentheses.

$^{+}p \leqq 0.1$, $^{*}p \leqq 0.05$, $^{**}p \leqq 0.01$, $^{***}p \leqq 0.001$; a: The changes between pre-test and post-test were treated as dependent variables while the pre-test scores were controlled as covariants; b: Perceived Restorativeness Scale;

[+] Significantly different from Heightened Awareness treatment;

[◈] Significantly different from Minimal and Moderate Awareness treatment;

[‖] Significantly different from No Tree treatment.

directed attention tasks than those who were not instructed to pay attention to them. Our results resonate with research suggesting that nature content impacts people without their own awareness, but the effect will be greater if it is combined with a mental or emotional activity that increases awareness (Kaplan, 2001; Korpela et al., 2002).

Regarding to the evaluation of the PRS, individuals who were told to observe the trees rated the landscape scenes higher for their sense of coherence and marginally higher in terms of scope. These findings might suggest a viewer who is more aware of natural features such as trees may see the landscape more favorably from a restorative perspective (Kaplan, 2001).

Although the assessment of some restorative characteristics was increased slightly by heightened awareness, the effects did not emerge for "*fascination*" or "*compatibility.*" One possible reason that the awareness of street scenes with or without trees made no difference for the sense of *fascination* is that the images used in the experiment were quite familiar and common place to all participants. Perhaps trees that were more novel would have had an impact on fascination. Assessing such a possibility is an area for future research. The familiarity of the streetscapes may have also moderated the sense of compatibility. It is also possible that our measure of compatibility did not adequately capture the true meaning of the metric. In future research, it would be best to evaluate *compatibility*, with a more specific prompt than the one used here—one that focuses participants on their goals at the moment.

These findings demonstrate that when the participants' awareness of the street trees is heightened, they were better able to pay attention after exposure to a green setting than their counterparts who did not have their awareness heightened. These findings resonate with Duvall's (2011), who had adults walk outdoors for 30-min three times per week. Participants were randomly assigned to either the standard walking group or a group that practiced awareness of their surroundings. After the 2-week experiment, individuals who practiced awareness of their surroundings scored significantly higher on multiple measures of psychological well being including their capacity to pay attention. In his awareness treatment, Duvall's participants focused on their senses, imaged a new job or role as they walked, made guesses or inferences about the setting, or could cast spells that changed the environment in some way or another. In our study, we asked participants to engage in an even less cognitively demanding task—we simply told them to pay attention to the vegetation along the street. That such a simple intervention could have such significant results suggests the power of directing one's awareness to aspects of the physical environment that are restorative.

These findings have broad implications. Urban planners, architects, and landscape architects can use these results to help create places that are more restorative for individuals. Beyond simply providing restorative settings, they can find creative ways to engage people to be aware of the restorative aspects of the built environment.

Educators, business professionals, hospital workers, and others whose work places great demands on their capacity to pay attention can also use these results. Through the simple act of being aware of trees, flowers, a water feature or other restorative elements in the built environment, individuals are likely to benefit to a greater extent from these elements than if they were to simply accept them as part of their surroundings.

LIMITATIONS AND FUTURE RESEARCH

By using simulated trees in the images shown to the participants, we were able to compare the differences between streetscapes with and without trees. The photographs used in the current study were taken from real streetscapes in Taipei, which are representative of densely populated urban environments. Future research should manipulate the density of the tree cover to see so that we might understand the interaction between a range of tree densities and heightened awareness.

Two other issues concern the expertise of our participants and their familiarity with the settings that were examined. Many of our participants had expertise in urban design, landscape architecture, or horticulture. Thus, they might not be representative of other adults who are not as focused on their physical surroundings. The interest of our participants in viewing green elements may be higher than that of untrained people, so the effect of green elements on their ability to recover their directed attention capacity might be enhanced compared to individuals who do not share these forms of expertise (Kaplan, 2001). Our participants were all students living in the city in which the pictures were taken. Some of the participants may have been familiar with the settings in the images. Future research should include participants from a variety of demographic backgrounds and education levels and also sample scenes with which none of the participants are familiar.

In this study, we found that awareness impacted attention. It seems possible that awareness of specific restorative elements in the landscape could also impact stress responses. A variety of studies have shown that exposure to natural elements in the landscape can help people recover from stressful events (Chang et al., 2008; Thompson et al., 2012; Tyrväinen et al., 2014). In these studies, awareness of the landscape was not a factor that was either manipulated or measured. To what extent does calling awareness to landscape features impact the speed of recovery from a stressful event? Given the results here, this is a question worthy of study.

Finally, more research should be done in real settings. In this study, we manipulated levels of awareness in a laboratory setting and found that awareness impacted attentional functioning. Future studies should manipulate levels of awareness in real-world settings as Duvall did (2011).

CONCLUSION

Our study answers an important question: To what extent does the awareness of street trees impact the restorative impact of a street scene? Results are reassuring: The restoration of directed attention requires minimal awareness—so small, in fact that participants did not realize that the trees were present. Heightened awareness, however, further increased restoration of directed attention and influenced ratings of restorative quality of the street scenes. Awareness may not be a necessary part of the restoration process, but the evidence presented here suggests it can play a role in enhancing restorative experiences.

The practical benefits of this research are clear. Since contact with nearby nature benefits physical, psychological, and social well-being (Matsuoka and Kaplan, 2008; Barton and Pretty, 2010;

Degenhardt and Buchecker, 2012; Thompson et al., 2012), the potential benefit of awareness clearly merits more attention. For individuals exposed to only minimal greenery in urban areas, heightened awareness may maximize the benefits of this minimal exposure.

Finding ways to encourage people to increase their awareness of restorative elements such as urban trees seems a worthy investment. Such an investment is likely to pay significant dividends for those of us in the world today who depend on our capacity to pay attention to meet our goals. That is to say, it is likely to pay dividends for most humans alive today.

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The great outdoors? Exploring the mental health benefits of natural environments

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There is growing evidence to suggest that exposure to natural environments can be associated with mental health benefits. Proximity to greenspace has been associated with lower levels of stress (Thompson et al., 2012) and reduced symptomology for depression and anxiety (Beyer et al., 2014), while interacting with nature can improve cognition for children with attention deficits (Taylor and Kuo, 2009) and individuals with depression (Berman et al., 2012). A recent epidemiological study has shown that people who move to greener urban areas benefit from sustained improvements in their mental health (Alcock et al., 2014). In this paper we critically review evidence indicating that such mental health benefits are associated with the so-called "restorative" properties of natural environments. In particular we focus on the claim that interaction with (or just passive *perception* of) natural scene content can be linked to the restoration of limited-capacity attentional resources, in comparison to similar exposure to urban or built scene content.

WHAT MAKES AN ENVIRONMENT RESTORATIVE?

Attentional restoration theory (ART) is an influential framework first proposed by Kaplan and Kaplan (1989) that claims urban environments suffer from an excess of bottom-up stimulation that serves to dramatically capture attention. People exposed to urban environments are forced to use their attention to overcome the effects of constant stimulation (described as *hard fascination*), and this in turn over time induces cognitive fatigue. In contrast, natural environments benefit from what the Kaplan's term *soft fascination*, which refers to scene content that automatically captures attention while simultaneously eliciting feelings of pleasure. Although there is no direct equivalent of hard and soft fascination in the cognitive attentional literature, the terms have been related to the concept of voluntary and involuntary attention (James, 1892). The process of soft fascination is seen to reduce the demand on executive-based attention, thereby allowing greater restoration of depleted attentional resources in comparison to the perception of urban environments (Kaplan, 1995, 2001). Kaplan and Berman (2010) have proposed that natural environments can restore directed attention; a common resource that supports both executive functioning and self-regulation processes in cognition (Baumeister et al., 1998; Norman and Shallice, 2000).

Other important features of restorative environments identified by ART include the experience of *being* away, in which a person feels a sense of escape from the stressful demands of daily life, and *extent*, in which a perception of vastness, and connectedness in an environment helps promote related experiences of "being away." Studies supporting ART have demonstrated improved performance on attention-demanding tasks following time spent in natural environments (e.g., Hartig et al., 1991; Berman et al., 2008). Intriguingly, attention restoration effects are also observed after participants simply watch films or photographs that depict natural scene content (van den Berg et al., 2003; Berto, 2005), implying that direct physical engagement with nature may be unnecessary to promote positive restoration effects.

ART has been widely cited in the literature as supporting superior health benefits of natural environments in comparison to urban environments. However, an important feature of ART that distinguishes it from more psycho-evolutionary frameworks such as that proposed by Ulrich (1983) is that the key informational elements such as *being away* and *fascination* that help determine restorative environments need not be *uniquely* associated with natural environments alone. For example, man-made structures such as monasteries can also be considered restorative environments (Ouellette et al., 2005). Although Korpela et al. (2001) have argued that restorative experiences are overrepresented in natural environments when students are asked to describe their favorite places, they notably allow within their definition of "natural" reference to man-made features such as "cottage surrounded by trees next to a lake" (p. 580). Residential and leisure environments (e.g., museums, art galleries) have also been claimed to reduce demands placed on executive attention and thereby promote psychological restoration (Staats, 2012). Findings such as these suggest that restorative properties associated with exposure to natural environments may not derive from intrinsic properties of the scene content itself, but instead from much broader contextual, and associative factors. The majority of studies reported in the literature tend to compare natural scenes against urban scenes, whether in the form of physical real-world environments or virtual depictions in films and photographs. Critically, we argue that careful stimuli selection for these types of studies is vitally important. There is a tendency to treat the categories of "natural" and "urban/built" as being more clearly defined and identifiable than may actually be the case in every-day judgments (van der Jagt et al., 2014). Indeed, in a study highlighting the importance of water in stimuli selection, White et al. (2010) point out that many studies in this area have demonstrated a bias toward the inclusion of aquatic scenes in the positive-natural category, and that urban scenes containing water were just as likely to elicit positive responses.

THE RELATIONSHIP BETWEEN PERCEIVED RESTORATIVE PROPERTIES AND ATTENTION-RESTORATION

Studies examining the relationship between exposure to natural scenes and attention restoration have used a variety of different tasks and measures of cognitive function in order to garner experimental evidence of any "attention restoration effect." Many studies involve inducing mental fatigue for a group of participants and then comparing that group with a non-fatigued group. For example, Hartig et al. (2003) induced mental fatigue by asking half of their participants to carry out a sequence of Stroop and binary classification tasks. van den Berg et al. (2003) played participants fragments of a distressing film to ensure that participants were suitably in need of restoration prior to carrying out the experiment, and other studies have used naturalistic fatigue induction protocols, such as sampling participants after lectures or exams (e.g., Hartig and Staats, 2006; Karmanov and Hamel, 2008), or have asked people to "imagine" that they are attentionally fatigued (e.g., Staats and Hartig, 2004).

Notwithstanding the method used to induce attention fatigue, it is important to distinguish between what might be termed "directed attention fatigue"—indicated by a lowering of performance on attention-demanding tasks, and other forms of fatigue such as those related to sleepiness, emotional stress or boredom. For example, the aforementioned study by van den Berg et al. (2003) induced stress via an emotionally distressing movie, but then went on to test for attention-restoration via a concentration index. A wide range of measures of cognitive function have been used to detect differences in attention-restoration, including: the backwards digit span task (e.g., Berman et al., 2008), the Necker cube pattern control task (e.g., Hartig et al., 2003), the symbol digit modalities test (e.g., Tennessen and Cimprich, 1995), and the attention network task (e.g., Berman et al., 2008). It is potentially problematic in drawing meaningful conclusions from studies if different concepts of what constitutes "stress" are conflated, or if alternative explanations such as motivation or mood effects are not sufficiently controlled for.

We also argue that an important distinction needs to be made between the perceived restorative properties of images or environments, and levels of *actual restoration* following direct experience with an environment. Various efforts have been made to develop scales that allow the perceived restorative potential of environments to be assessed, including the Perceived Restorativeness Scale (Hartig et al., 1997), the Restorative Components Scale (Laumann et al., 2001), and the Perceived Restorative Characteristics Questionnaire (Pals et al., 2009). All of these measures attempt to measure the restorative components of environments as specified by ART, and they are useful insofar as they help to understand the underlying dimensions of environmental preference and associated behavioral choice. However, we argue that the extent to which perceived restoration predicts *actual* restoration is undervalued in the literature. There is an assumption that individuals have sufficiently high metacognitive understanding of their own cognitive processes that they can accurately estimate how different environments will affect them. There is surprisingly little direct evidence for this, and in other areas of cognition such as memory or perception people can be poor at accurately predicting their own performance (e.g., Bona and Silvanto, 2014; Roediger and DeSoto, 2014). Furthermore, if ART is correct and restoration results from an interaction between directed attention and the intrinsic properties of an environment, such restoration should occur irrespective of whether it has been previously "perceived" or not. If perceived restoration measures are used in the absence of any hard evidence for related cognitive effects, we argue there is a potential risk that the true restorative potential of natural, and urban environments could be misrepresented.

WHAT IS THE OPTIMAL FORM OF INTERACTION WITH RESTORATIVE ENVIRONMENTS?

Although Stamps (1990) suggests that static photographs are sufficiently valid representations in allowing aesthetic judgments to be made, forming an aesthetic judgment of an image is somewhat different to judging the wider qualities of the environment depicted in the image. That said, even when focussing on aesthetic judgments, simply adding a degree of dynamism can significantly affect the ratings of preference for scenes (Heft and Nasar, 2000). If simply adding dynamism to environmental depictions affects preference, then it seems reasonable to expect that greater degrees of interaction will play an important role in terms of the mechanisms that environments can be thought of as facilitating psychological restoration. Do people need to physically interact with nature to receive the apparent health benefits, or is passive visual exposure to films sufficient? de Kort et al. (2006) suggest that "immersion" is an important component of the person-environment interaction in terms of psychological restoration, and that virtual environments can potentially be used to create a reasonable analog in order to study these important questions more fully. However, the closer that technology allows studies to approximate visual and experiential reality, the more questions can be asked about what is missing from such simulations in comparison to real environments. When studies suggest that large television displays (Friedman et al., 2008) or large wall murals (Felsten, 2009) could potentially form part of a future built environment where windows are not possible (e.g., in basements), or where the view from a window is rather mundane, the implications for the preservation of urban greenspace could be quite stark if simulations are judged to have the same restorative properties as real environments. However, studies that have directly compared simulated and real environments on their restorative properties suggest they are not equivalent (Martens and Bauer, 2008; Kjellgren and Buhrkall, 2010). Notwithstanding some of the methodological challenges with carrying out these types of research studies, they serve an additionally important function insofar as they force us to think more about the deeper philosophical issues at the heart of human-nature relationships.

CLOSING COMMENTS

The growing trend for urbanization means the majority of the world's population are spending less time exposed to natural environments. This trend has potentially very serious implications for health if exposure to natural environments is causal to short-term recovery from stress or mental fatigue, and to overall long-term improvements in health and well-being. If the postulated causal relationship between natural environments and mental health is correct, then increasing accessibility to well-maintained greenspace and instigating behavior change programs that encourage greater interaction with nature could deliver substantial short and long-term benefits to mental health. However, much of the existing evidence base is based on an arguably too simplistic "natural" and "built" dichotomy. The importance of people's attitudes and beliefs toward health and the environment, and how these may interact with behavioral and physiological responses, is in particular poorly represented by the existing evidence base.

In closing, we therefore suggest that there is a pressing need for more empirical research that has the specific aim of establishing: (1) which properties of environments make them more or less "restorative"; (2) the relationship between perceived restorative properties of an environment and objective measures of improved cognitive function; and (3) the optimal form of interaction with restorative environments that is most likely to lead to mental health and well-being benefits.

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Urbanization increases left-bias in line-bisection: an expression of elevated levels of intrinsic alertness?

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Urbanization impairs attentional selection and increases distraction from task-irrelevant contextual information, consistent with a reduction in attentional engagement with the task in hand. Previously, we proposed an attentional-state account of these findings, suggesting that urbanization increases intrinsic alertness and with it exploration of the wider environment at the cost of engagement with the task in hand. Here, we compare urbanized people with a remote people on a line-bisection paradigm. We show that urbanized people have a left spatial bias where remote people have no significant bias. These findings are consistent with the alertness account and provide the first test of why remote peoples have such an extraordinary capacity to concentrate.

Keywords: attention, engagement, control, alertness, spatial attention, spatial bias, laterality, urbanization

INTRODUCTION

Remote peoples living in natural environments have an extraordinary capacity for attentional selection of task-relevant material. They show substantially reduced interference from task-irrelevant information, even to the point where a highly salient distractor (such as a motion singleton) exerts no significant interference (de Fockert et al., 2011). Furthermore, their capacity for selection exceeds that of urbanized controls even when distracting information is more salient to them than to controls: thus, despite their having a perceptual bias to process local information, they show less interference from distracting local information when selecting global information than urbanized controls (as well as less interference from distracting global information when selecting local information; Caparos et al., 2013). In sum, remote peoples are better able to focus their attention on the task in hand. What is more, they are even able to focus on easy tasks (of low perceptual load; Linnell et al., 2013) where attentional engagement is supposed to be limited (Kahneman, 1973). Here we set out to provide the first test of why remote peoples should have such an extraordinary capacity to concentrate.

Specifically, we examine our previous speculation that remote peoples have middling levels of intrinsic alertness[1], optimally suited to task engagement and the selective processing of task-relevant stimuli, while urbanization increases intrinsic alertness, and with it exploration and the processing of task-irrelevant contextual stimuli (Linnell et al., 2013). This speculation is based on the model of Aston-Jones and colleagues (e.g., Aston-Jones et al., 1999; Aston-Jones and Cohen, 2005) and related work (for a review, see Singh-Curry and Husain, 2009) suggesting that exploration and task engagement represent different ways of interacting with the world, distinguished only by different underlying levels of intrinsic alertness. According to the model, intrinsic alertness is expressed by tonic activity in the locus coeruleus-norepinephrine system (LC-NE). Whereas low tonic activity in the LC-NE system—low alertness—is linked to low sensitivity to external stimuli and leads to drowsiness, high tonic activity—high alertness—is linked to high sensitivity to external stimulation and leads to exploration. A middling level of tonic activity—middling alertness—leads to task engagement by enabling selective or phasic activity in the LC-NE system that is time-locked to the presentation of task-relevant stimuli. The model shows that this phasic activity[2] is reduced if tonic activity is either too low or too high—in states of low or high intrinsic alertness, respectively. In other words, the model results in task engagement following an "inverted-U" function of intrinsic alertness. This is, in essence, a restatement of the Yerkes–Dodson law (Yerkes and Dodson, 1908) where task performance (as driven by task engagement) first improves and then falls off with increasing alertness/arousal (see **Figure 1**).

Can the extraordinary capacity of remote peoples to engage with the task in hand be explained by this variant of the Yerkes–Dodson law? According to the model, task engagement predominates when intrinsic alertness is at middling levels, and exploration predominates when it is at high levels. The dynamic range of the model is obviously critical to accommodating both resting and stress conditions; however, the proposal which we set

[1] Here we use intrinsic alertness to signify internally controlled wakefulness or arousal.

[2] Phasic activity here can be equated with extrinsic alertness, insofar as extrinsic alertness is defined as the phasic response to external stimuli (driven by tonic activity/internally controlled wakefulness or arousal), as opposed to externally controlled wakefulness or arousal (driven, for example, by alerting cues).

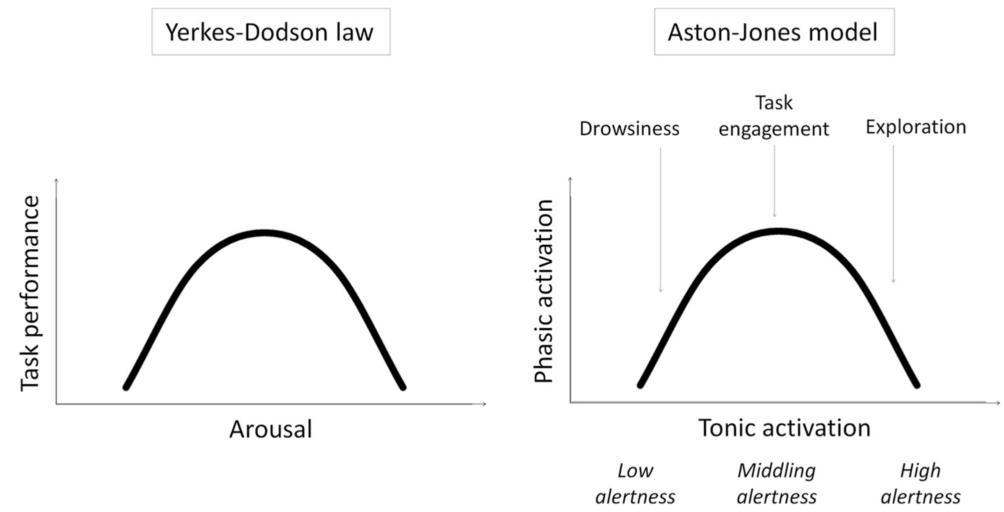

FIGURE 1 | Schematic illustrations of the Yerkes–Dodson law and the Aston-Jones model and the parallels between them.

out to test here is that urbanization induces, probably through stress-related effects (Lederbogen et al., 2011), elevated levels of intrinsic alertness even under resting conditions and thus shifts the balance in favor of exploration and away from task engagement. This proposal is plausible given the studies showing that stress increases tonic activation in the LC-NE system (for a review, see Aston-Jones et al., 2007).

In order to test the intrinsic-alertness hypothesis, we rely on the right lateralisation of the system that mediates alertness (e.g., Sturm et al., 1999; He et al., 2007; Corbetta and Shulman, 2011). We invoke findings showing that, because of this lateralisation, changes in intrinsic alertness affect relative hemispheric activation patterns and, as a result, left-right spatial biases (Newman et al., 2013). Specifically, decreasing intrinsic alertness with time-on-task results in rightwards moving spatial biases (Manly et al., 2005). Equally, decreases in intrinsic alertness due to sleep deprivation and/or disruption of the circadian rhythm, as well as approaching the nadir of the circadian rhythm, or being on the point of falling asleep, also result in rightwards moving spatial biases (Manly et al., 2005; Schmitz et al., 2011; Bareham et al., 2014). Conversely, interventions that increase intrinsic alertness, whether by phasic alerting or the administration of stimulants, result in leftward moving spatial biases (e.g., Robertson et al., 1998; Sheppard et al., 1999).

Here we reason that if urbanization increases intrinsic alertness it should also shift spatial biases leftward. We compared spatial biases in urbanized and remote groups using the same behavioral paradigm employed in most of the studies reviewed above. Specifically, we used the line-bisection paradigm in a variant called the Landmark test (Milner et al., 1992; Manly et al., 2005) that has been advocated as the most sensitive measure of spatial bias (Jewell and McCourt, 2000). In this paradigm, the subjective midpoint of horizontal lines is measured by presenting transected lines and asking participants to indicate whether the part of the line left or right of the transector appears longer; the direction of any deviation of the perceived midpoint from veridical center reflects greater activation in the contralateral hemisphere, the more so the greater the extent of the deviation (Newman et al., 2013).

The subjectively judged midpoint or point of subjective equality (PSE) measured with this paradigm generally falls left of center, even in high-functioning (urbanized) participants tested under optimal conditions. This phenomenon is known as pseudo-neglect to contrast it with the well-known and very extensive rightward bias in neglect patients with right-hemisphere lesions (which notably ameliorates with phasic alerting; Robertson et al., 1998). Though pseudo-neglect is a rather surprising phenomenon, it is widely accepted as the norm, albeit an anomalous one, and its origin has been little researched (Jewell and McCourt, 2000). If we are correct in our suggestion that urbanized peoples have elevated levels of intrinsic alertness that are too high to promote optimal task engagement, whereas remote peoples have more middling intrinsic alertness, then remote peoples should bisect rightwards of urbanized peoples and show reduced and possibly even absent pseudo-neglect.

METHODS

We measured left-right perceptual bias using the Landmark version of the line-bisection task (Milner et al., 1992; Manly et al., 2005) advocated by Jewell and McCourt (2000).

PARTICIPANTS

The urban participants were British students from London, UK. The remote participants were Himba individuals, living in traditional villages in the open savannah of north-west Namibia. All Himba participants were monolingual (in Otjiherero) and had had little contact with the Western world; on average, they had been to Opuwo (the only town in the region) only 2.5 times (s.e.m. = 0.4) in their lifetime. To our knowledge, none of the Himba had ever been involved in experimental research before.

Fifty-six British (38 females, mean age = 25.6 years, age range = 17–43 years) and 56 Himba participants (33 females, mean age = 25.4 years, age range = 17–42 years), matched in

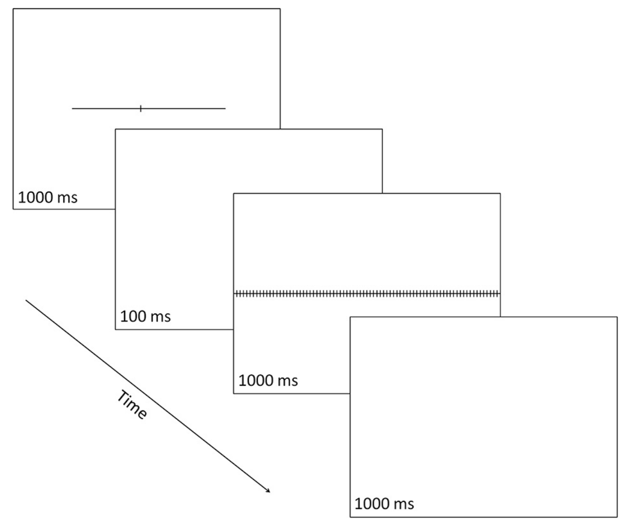

FIGURE 2 | A schematic illustration of a single trial in which the line transector fell to the left of line center and the correct response was a right button-press signaling that the part of the line that was longer was the right one. Numbers indicate exposure durations in milliseconds (ms).

terms of (1) time of testing and (2) age took part in the experiment. Testing took place between 10.03 am and 4.04 pm local time (mean time = 12.48 pm) with the British participants, and between 10.01 am and 3.58 pm local time (mean time = 12.44 pm) with the Himba participants.

Participants were paid or rewarded in kind (with flour and sugar).

STIMULI

Stimuli were modeled on those used in Manly et al. (2005) and were presented using E-Prime 1.0 (Schneider et al., 2002) on a 20-in CRT monitor (SONY Trinitron F520) at a viewing distance of 70 cm.

Stimuli consisted of transected lines, the target stimuli, each followed by a mask. Both target stimuli and the mask were presented in black on a white background along the horizontal midline of the screen.

Each target stimulus was a horizontal line subtending 18.8° (or degrees of visual angle) in length and 0.1° in width, and transected by a small vertical line subtending 0.8° in length and 0.1° in width (see **Figure 2**). The vertical line could transect the horizontal line at one of seven possible locations, thus creating seven different target stimuli defined by the length of the horizontal-line parts left and right of the transector. Three targets had a left part longer than the right part (i.e., 10.4° vs. 8.4°, 10.0° vs. 8.8°, or 9.6° vs. 9.2°, respectively), one target had left and right parts equal in length (i.e., 9.4° vs. 9.4°) and three targets had a left part shorter than the right part (i.e., 9.2° vs. 9.6°, 8.8° vs. 10.0°, or 8.4° vs. 10.4°, respectively). Each of the seven types of target stimuli was equally often presented centered at the vertical midline of the display, jittered 1.1° to the left, or jittered 1.1° to the right, creating 21 distinct target displays.

The mask was a horizontal line that stretched from the left to the right edge of the CRT along the horizontal midline. It was crossed by 86 equidistant vertical lines, each subtending 0.8° in length and 0.1° in width and separated from each other by 0.4°.

PROCEDURE

On each trial, the target stimulus, the transected line, was shown for 1000 ms and was followed by a 100-ms blank; then the mask was shown for 1000 ms, followed by a 1000-ms blank, after which the next trial started (even if the participant has not made any response). Responses could be made at any point during each trial after the onset of the transected line. The participant made a two-alternative forced-choice (2-AFC) response to indicate which part of the line (left or right) was longer: using a two-button response box, s/he pressed the left button (with their left hand) to indicate a "left" choice or the right button (with their right hand) to indicate a "right" choice.

Before starting the test trials, participants completed a 10-trial practice session in which the left and right parts of the target were distinctly different (i.e., they measured, respectively, 10.8° and 8.0°, or 8.0° and 10.8°). During the subsequent test phase, each of the 21 distinct target displays described above was presented four times, in randomized order.

Testing with the Himba participants took place on the outskirts of traditional Himba villages, inside a large testing tent placed in a shaded area. Testing with the British participants took place inside a quiet and moderately lit testing room in London, UK. For the Himba, instructions were given with the help of an interpreter who was naive to the purpose of the study.

RESULTS

For each participant, the mean percentage of "right part is longer" responses was calculated for the seven target lines defined by the position of the transector relative to the line. The task was well performed: all participants produced accuracies in excess of 90% for the most extreme line bisections in the test phase, showing that they understood the task (see **Figure 3** illustrating the group psychometric functions).

For each participant, the PSE was computed (in degrees of visual angle), defining their threshold for deciding that the right side of the transected line was longer than the left side [3]. Negative PSEs indicated that participants perceived the middle of the line to fall to the left of veridical center (i.e., consistent with the "pseudoneglect" pattern of bisection typical of healthy urbanized participants). In contrast, positive PSEs indicated that participants perceived the middle of the line to fall to the right of veridical center (i.e., consistent with the "neglect" pattern of bisection).

[3]We fitted the data for each participant with the model: $p = \varphi([k–d]/\sigma)$, where p is the probability of choosing the larger part of the target, $\varphi(z)$ is the inverse cumulative distribution function for a standard normal distribution, k is the required threshold for deciding that the larger part of the target was the larger one, d is the length difference between the two parts of the target (in degrees of visual angle) and σ is the standard deviation of the normally distributed noise from all sources.

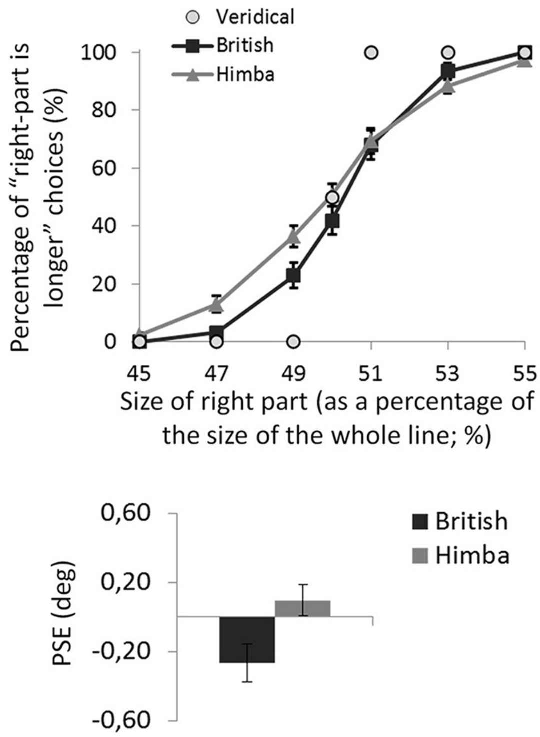

FIGURE 3 | A graph comparing the psychometric functions and group mean line-bisection PSEs for urbanized (British) and remote (Himba) groups. Error bars depict ±1 s.e.m.

An independent-samples t-test showed that British participants had significantly lower PSEs than Himba participants, $t_{(110)} = 2.2$, $p = 0.033$, $d = 0.410$ (see **Figure 3**). While British participants had PSEs significantly lower than zero (i.e., they bisected significantly to the left and thus displayed pseudo-neglect), $t_{(55)} = 2.7$, $p = 0.010$, $d = 0.497$, the PSE of Himba participants was not significantly different from zero or veridical center, $t_{(55)} = 0.7, p = 0.476, d = 0.136$. Indeed, these PSE-based findings are supported by focusing on performance with just the perfectly bisected lines (Manly et al., 2005). The Himba participants judged the right side of perfectly bisected lines to be longer than the left 51% of the time in contrast to the British participants who judged the right side to be longer 42% of the time.

If these spatial biases are really due to alertness differences, they ought to be affected by time of testing. Almost exactly half our participants were tested before 1 pm local-time and almost exactly half after 1 pm (with Himba and British participants pair matched for exact time of testing). **Figure 4** shows the psychometric functions for both groups split by time of testing (namely, before and after 1 pm). For the PSEs, there was a significant interaction between group and time of testing, $F_{(1,\ 108)} = 4.2, p = 0.042$, $\eta_p^2 = 0.038$, such that there was a significant group difference earlier in the day, $t_{(55)} = 2.7$, $p = 0.009$, $d = 0.697$, that vanished later, $t_{(55)} = 0.1$, $p = 0.917$, $d = 0.040$[4]. The group difference early in the day was founded on the fact that, while British participants showed a significant leftward bias ($M = -0.42$, s.e.m. $= 0.16$), $t_{(28)} = 2.5$, $p = 0.017$, $d = 0.660$, Himba participants did not show a significant bias ($M = 0.28$, s.e.m. $= 0.17$), $t_{(26)} = 1.4$, $p = 0.174$, $d = 0.360$. Later in the day, neither British participants ($M = -0.10$, s.e.m. $= 0.17$) nor Himba participants ($M = -0.08$, s.e.m. $= 0.16$) showed a significant bias, respectively, $t_{(28)} = 1.0$, $p = 0.322$, $d = 0.255$, and $t_{(28)} = 0.4$, $p = 0.666$, $d = 0.104$. **Figure 4** shows that the PSE-based findings are again supported by performance with just the perfectly bisected lines.

[4]Time of testing effects were not significant for either group.

GENERAL DISCUSSION

Performance on the Landmark version of the line-bisection task (Milner et al., 1992; Manly et al., 2005) differed significantly between remote (traditional Himba) and urbanized (British) participants with similar age and gender spread and tested at matched times of day. While overall the urbanized group bisected significantly to the left of center, replicating the standard pseudo-neglect phenomenon (Jewell and McCourt, 2000), the remote group produced bisections that were, if anything, right of veridical center although they did not differ significantly from veridical performance (see **Figure 3**).

While our findings are consistent with remote peoples having less activity in the right-lateralised system mediating alertness—that is lower levels of intrinsic alertness—than urbanized groups, we must also consider alternative or additional explanations for our findings. Although alertness does indeed influence line-bisection performance in systematic ways (e.g., Manly et al., 2005), there are other factors that are known to influence it which we must consider, notably age, time of day, and reading direction (see Jewell and McCourt, 2000, for a review). While we controlled for the first two, we could not control for the last: the traditional Himba that we tested were all illiterate, whereas our British controls all read from left to right. Despite the fact that the research on reading direction is inconclusive (e.g., Chokron et al., 1998; Nicholls and Roberts, 2002), experience with left-to-right scanning in our British participants could have produced a slight leftwards bias absent in the Himba. We argue, however, that this possibility is inconsistent with the fact that the Himba and British spatial biases were indistinguishable in the latter part of the day (see **Figure 4**). More generally, the sensitivity of the group difference in spatial bias to time of day is difficult to explain in terms of other factors that may vary between groups and that are lateralized (and that could in theory produce group differences in spatial bias) but that should not vary with time of day, except of course if they are driven by alertness differences (e.g., global-local bias; Caparos et al., 2012). Similarly, the time-of-day effects seem to rule out the possibility that it is attentional engagement itself that explains the group differences in bisection (such that increased engagement in remote groups produces more veridical bisections) since there is no reason to suppose that engagement should vary with time of day except if, as we propose here, it is driven by alertness. While we cannot completely rule out the influence of other factors, it is most parsimonious to argue that the pattern of spatial biases that we report here originates in group differences in overall intrinsic alertness which are linked to

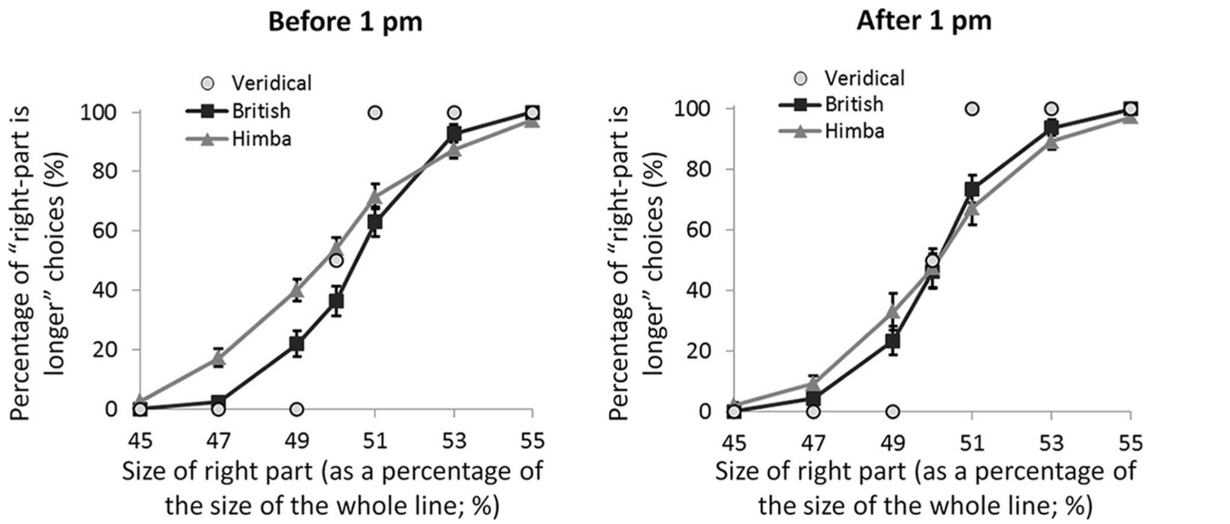

FIGURE 4 | A graph comparing the psychometric functions for urbanized (British) and remote (Himba) groups, both before 1 pm and after 1 pm. Error bars depict ±1 s.e.m.

different patterns of diurnal variation in alertness (e.g., Thayer, 1989).

In future work comparing remote and urbanized groups, it will be important to collect more direct markers of intrinsic alertness and attentional engagement, and of the balance between tonic vs. phasic activity in the locus coeruleus-norepinehrine (LC-NE) system. A behavioral proxy for activity in the LC-NE system which is amenable to field testing is pupil dilation (Gilzenrat et al., 2010). For example, Smallwood and colleagues (e.g., Smallwood et al., 2011) have shown that increasing task difficulty decreases baseline pupil dilation and increases task-related pupil dilation. This is consistent with increasing task difficulty motivating a decrease in tonic LC-NE activity/alertness and an increase in phasic LC-NE activity/task engagement. Combining the present finding that remote groups show reduced leftward spatial biases with previous findings that they can engage attention even on easy tasks of low load (Linnell et al., 2013), leads us to the prediction that—in easy as in hard tasks—their baseline pupil dilation will be low and their task-related increases in pupil dilation high.

Pending such direct evidence, we interpret our present findings as being consistent with remote groups having lower intrinsic-alertness levels than urbanized groups. Thus, the greater task engagement and immunity to distraction of remote peoples (de Fockert et al., 2011; Caparos et al., 2013; Linnell et al., 2013) seems to be associated with decreases in intrinsic alertness. This interpretation allows us to discount the very important possibility that the previously reported increased engagement of remote peoples was an artifact of the novelty of the testing situation (whether arising from the use of luminous displays and other electronic gadgetry or the different ethnicity and lifestyle of the experimenters). Novelty is arousing and should increase alertness not decrease it (e.g., Yanaka et al., 2010). Rather, the greater task engagement and immunity to distraction of remote peoples seems to be associated with levels of intrinsic alertness that are lower than those in urbanized groups. As outlined in the introduction to this manuscript, this is compatible with previous suggestions that attentional engagement is optimal at middling levels of intrinsic alertness and falls off with higher levels (Yerkes and Dodson, 1908; Aston-Jones and Cohen, 2005; Singh-Curry and Husain, 2009). It opens the door to the possibility that the standard leftward-bisection bias in the healthy (urbanized) populations reported in the literature is not a reflection of a "natural" state but rather of a hyper-vigilant one (albeit not as extreme, for example, as that in powerless urbanized people; Wilkinson et al., 2010). In this context, it is noteworthy that leftward biases in non-remote groups have only been reported to arise in early adolescence; while it has been speculated that the late expression of the leftwards bias is an artifact of the delayed development of the corpus callosum (Hausmann et al., 2003), its timing could be linked to the age at which urbanization first results in elevated levels of intrinsic alertness/hemispheric imbalances. It is also noteworthy that participants who are high in mindfulness, and who like the remote group presented here exhibit increased attentional control (e.g., Jha et al., 2007), also exhibit more balanced hemisphere-activation patterns (Aftanas and Golosheykin, 2005).

If the pseudo-neglect and hemispheric asymmetry in urbanized groups does reflect elevated intrinsic alertness, the next question we need to answer is whether the increase in alertness is reversible. It is tempting to conclude that it is and to speculate that the restorative effects of short-term exposure to the natural environment on cognitive function (Kaplan, 1995; Berman et al., 2008) are also linked to reductions in intrinsic-alertness levels. However, this and other analogies between short-term reversible effects and the effects reported here must be treated with extreme caution given that urban upbringing has been reported to impact different aspects of the alerting network to more short-term urban living (Lederbogen et al., 2011). Thus, it is possible that urban exposure exerts both non-reversible and reversible effects and that these effects are underpinned by different mechanisms.

In sum, our findings are consistent with remote groups having reduced intrinsic-alertness levels compared to urbanized ones. The dynamic and unpredictable nature of the urban environment may make increased alertness and exploration more adaptive for urban groups but this may come at the cost of reduced immersion in the "here and now" of the task in hand. In contrast, remote groups appear to be able to engage their attention even on easy tasks (low in perceptual load; Linnell et al., 2013) that have previously been thought to be incapable of engaging us (Kahneman, 1973) and to remain undistracted even by the most salient (movement-singleton) distractors (de Fockert et al., 2011) that have previously been reported always to distract us (Theeuwes, 2010). Remote groups may show us that optimizing intrinsic-alertness levels for task engagement (Yerkes and Dodson, 1908; Aston-Jones and Cohen, 2005) can support attentional performance that outstrips the limits of what has heretofore been thought possible.

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Is the preference of natural versus man-made scenes driven by bottom–up processing of the visual features of nature?

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Previous research has shown that viewing images of nature scenes can have a beneficial effect on memory, attention, and mood. In this study, we aimed to determine whether the preference of natural versus man-made scenes is driven by bottom–up processing of the low-level visual features of nature. We used participants' ratings of perceived naturalness as well as esthetic preference for 307 images with varied natural and urban content. We then quantified 10 low-level image features for each image (a combination of spatial and color properties). These features were used to predict esthetic preference in the images, as well as to decompose perceived naturalness to its predictable (modeled by the low-level visual features) and non-modeled aspects. Interactions of these separate aspects of naturalness with the time it took to make a preference judgment showed that naturalness based on low-level features related more to preference when the judgment was faster (bottom–up). On the other hand, perceived naturalness that was *not* modeled by low-level features was related more to preference when the judgment was slower. A quadratic discriminant classification analysis showed how relevant each aspect of naturalness (modeled and non-modeled) was to predicting preference ratings, as well as the image features on their own. Finally, we compared the effect of color-related and structure-related modeled naturalness, and the remaining unmodeled naturalness in predicting esthetic preference. In summary, bottom–up (color and spatial) properties of natural images captured by our features and the non-modeled naturalness are important to esthetic judgments of natural and man-made scenes, with each predicting unique variance.

Keywords: esthetic preference, natural scenes, urban scenes, bottom–up processing, image features, perceived naturalness

Introduction

Previous research has shown that interacting with natural environments such as walking in a park or viewing images of nature can have a beneficial effect on memory, attention, and mood (Berman et al., 2008, 2012) as well as other psychological and physical health benefits (Ulrich, 1984;

Kuo and Sullivan, 2001a,b; Cimprich and Ronis, 2003; Kaplan and Berman, 2010). Typically, the positive effects of interacting with nature are compared to the effects of interacting with urban or built environments. One reason that interacting with natural environments has been hypothesized to be beneficial comes from Attention Restoration Theory [ART; (Kaplan, 1995, 2001; Kaplan and Berman, 2010)]. ART claims that most natural environments do not tax top–down directed-attention mechanisms in the same way that many urban environments do, and they also provide softly fascinating stimulation that captures bottom–up involuntary attention mechanisms. It is this duality that is purported to make many natural environments restorative.

What is unclear, however, is why simply viewing pictures of nature vs. pictures of urban environments may lead to these benefits. Presumably, pictures of these environments would not capture attention in the same way as interacting with the actual environments, and yet researchers have found beneficial effects from simply viewing pictures of nature (Berto, 2005; Berman et al., 2008). The fact that pictures can elicit similar effects suggests that there may be low-level visual regularities of natural environments that may lead to psychological benefits. Alternatively, the very *semantic* idea of nature could be restorative. In other words, we might be "programmed" to benefit from low-level visual regularities in natural scenes in a bottom-up way, possibly imposed on our perceptual system through the process of natural selection. (See "savanna hypothesis" by Orians, 1986; Geisler, 2008).

In order to pave the way for future studies that will directly test this possibility, we first need to determine what the salient features that distinguish natural and urban scenes are and how these differential features may contribute to our preference for nature. Here we set out to determine the contribution of low-level statistical features versus semantics to esthetic preference judgments of natural vs. urban scene images. We do so by assessing the effects of bottom-up perceptions of naturalness that are driven by visual features of natural environments, e.g., the color green vs. perceptions of naturalness that cannot be predicted with certain low-level visual features and are possibly related to experience and semantic knowledge that affect one's judgment more deliberately and slowly.

While preference may not necessarily correlate with the salubrious effects that are attributed to natural environmental interventions, it is an important starting point, since no single image is likely to produce restorative benefits on its own (i.e., it is likely that a set of images would be necessary). We already know that natural images are preferred over man-made scenes (Kaplan et al., 1972). In this study our main goal is to estimate how much of the preference of natural images is due to bottom–up visual regularities of natural scenes.

The first empirical research leading to models of statistical esthetics was probably conducted by Fechner (1876) concerning the golden ratio. He suggested that principles of esthetics could be inspected through statistical analysis, and that esthetic preference works in a bottom–up manner. Birkhoff (1933) formulated a simple "Esthetic Measure" based on his studies of polygons, and he proposed that the esthetic pleasure derived from an object is a direct function of the number of ordered elements (symmetry, equal sides, equal angles, etc.) and an inverse function of the number of complexity elements (number of sides, re-entrant angles, etc.) that attract a viewer's attention. The simple square for example, had a very high degree of "Esthetic Measure" since it had both a high degree of order and a low degree of complexity. Eysenck (1957), on the other hand, argued that Esthetic Measure was the product and not the ratio of order and complexity because he found that preferred visual objects in his studies seemed to have both a high degree of order and complexity. More recently, information theory's quantitative measures of complexity (e.g., Kolmogorov complexity) and measures of information redundancy (entropy) have been applied to esthetics (Rigau et al., 2008; Graham and Redies, 2010).

In addition, fractal-like statistics that are a statistical regularity in natural images have been shown to play a role in esthetic perception (Aks and Sprott, 1996; Spehar et al., 2003). For example, Aks and Sprott (1996) created chaotic patterns using mathematical equations with unpredictable solutions and showed that the fractal dimension (the extent to which the space is filled with details) and the Lyapunov exponent of the patterns (degree of unpredictibility of pattern production) correlate with esthetic preference of the pattern, and that preferred patterns have similar fractal dimensions to natural objects. Lastly, color-related features of scenes, including brightness, could be important to perception and esthetic preference (Mureika, 2005; Palmer and Schloss, 2009; Wallraven et al., 2009; Graham and Redies, 2010; Masuda and Nascimento, 2013). For example, Masuda and Nascimento (2013) showed that for daylights, colorful images of food counters are perceived as more natural under illuminants with an average correlated color temperature (CCT) of 6040 K and are most preferable under illuminants with an average CCT of 4410 K.

Another dimension of the scenes that is of interest in our study is the perception of naturalness. In parallel to esthetics, the quantification of statistical regularities in nature and how they are sensed or perceived have been the subject of interest for many researchers in computer vision (Ruderman, 1994; Huang and Mumford, 1999; Oliva and Torralba, 2001; Torralba and Oliva, 2003; Fei-Fei and Perona, 2005), mammalian vision (Field, 1987; Baddeley and Hancock, 1991; Olshausen and Field, 1996; van Hateren and van der Schaaf, 1998), and also in the context of ART (Berman et al., 2014). In this study, we sought to investigate the involvement of statistical regularities of nature in the esthetic judgments of different environments. We attempted to isolate more bottom–up aspects of perceived naturalness predicted by visual features from other factors that affect perception of naturalness in a scene. We hypothesized that if we regressed the naturalness ratings of the scenes from the low-level visual features of the scenes, the predicted values would be related to the more bottom–up aspects of judgments of naturalness (i.e., the low-level visual features impact on perceptions of naturalness).

There are many ways to decompose images into low-level visual features or descriptors. In this study, we were specifically interested in edge-related visual features [such as total edge density (ED), non-straight edge density and straight (SED) that capture contrast changes in surfaces, borders, and shades], entropy that is related to the shape of the histogram of pixel values in the image, and color related visual features such as average hue, saturation, brightness, and their average variations (standard deviations) that capture the main spectrum of colors in the scene and their variations. This focus stems from our previous research (Berman et al., 2014), which has shown that these visual features can reliably predict the perception of naturalness in images of urban, natural, and mixed urban/natural environments.

The goal of the present study was to explore the relationships between these quantified color and spatial image features and people's esthetic preferences for the images, and then to estimate how much of the preference of nature images is due to bottom–up visual regularities of more natural images compared to the other aspects of natural scenes that are not modeled by these low-level visual features. With this knowledge, we may be able to isolate the effect of low-level features that occur in natural environments on judgments of preference from the more top–down semantics of naturalness. This information could then be used in the design of built environments to motivate interaction with nature and also improve psychological functioning.

Materials and Methods

Participants

All participants consented to voluntary participation via the guidelines established by the Institutional Review Board at the University of South Carolina and New Mexico State University. A total of 52 participants were enrolled in the experiment (26 female, mean age = 21.1). All participants reported normal or corrected-to-normal vision, and none reported any psychological or physical deficits that would exclude them from participation.

Materials

Three hundred and seven images consisted of a spectrum of natural to man-made scenes (scenery of Nova Scotia, urban parks from Annapolis, Baltimore and Washington D.C., and pictures of Ann Arbor, Detroit, and Chicago) were used in the experiment. The pictures of Nova Scotia, Ann Arbor, Detroit, and Chicago were taken from Berman et al. (2008, 2014) and the images from Annapolis, Baltimore, and Washington, D.C., were provided by the TKF foundation and were utilized in Berman et al. (2014). All of the images can be downloaded from our PLoS ONE publication Berman et al. (2014): http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0114572

This sample size provides sufficient statistical power for the study while keeping the behavioral experiments' duration reasonable (less than 40 min). The images were in three different sizes: 512*384, 685*465, and 1024*680 pixels. Importantly, all image features were normalized to the size of the images by being divided by the total number of pixels in the image.

Procedure

Images were presented to participants using PsychoPy (Peirce, 2007) experimental software on a desktop computer. The experiment consisted of two tasks. In one task, participants were instructed to rate how much they liked each scene using a standard Likert scale from 1 to 7, with '7' indicating a strong preference and '1' indicating a strong dislike. During this procedure, images were shown for 1 sec and then removed from the screen and participants had up to 4 sec to rate each scene. This was to prevent long preference judgments, which could lead to contamination of decision with uncontrolled semantics or personal experiences.

In the second task, participants were instructed to rate how natural versus man-made each scene was. Again, a Likert scale was used with a range from 1 to 7, with '7' indicating that the image was very natural and '1' indicating that the image was very man-made. During this task, participants viewed the scene for 1.5 s before they were able to respond. This was to prevent hasty judgments about natural content before examining the image properly. After 1.5 s the scene stayed on the computer screen so that participants could view it until they made their response.

The order of presentation for 307 images was always randomized. For both tasks, participants responded using the numbers 1–7 on the computer keyboard. The order of performing the two tasks was counterbalanced across participants (26 participants did preference rating first, and the other 26 did naturalness rating first). Participants were instructed about each rating experiment separately and did not know about their second experiment before finishing the first rating. There was a 1- to 2-min rest between the two rating experiments.

Behavioral Measures

Esthetic preference (Preference) for each image was calculated as the mean preference rating across all participants. Perceived naturalness (Naturalness) was also calculated as the mean naturalness rating across all participants for each image. The reason that ratings were averaged over all participants was that simple t-test comparisons showed that for none of the images the average preference from the 26 participants who did preference rating before naturalness rating was significantly different from the average preference rating from the 26 participants who did preference rating after naturalness rating (among all images, the closest to significance had $p = 0.103$, $t = -1.692$, df = 25). The same was true for naturalness ratings (among all images, closest to significance had $p = 0.202$, $t = -1.312$, df = 25).

Quantitative Image Analysis Measures

Color Properties

In this section we describe the color features that were used in our analysis. Color properties of the images were calculated based on the standard HSV model (Hue, Saturation, and Value) using the MATLAB image processing toolbox built-in functions (MATLAB and Image Processing Toolbox Release 2012b, The MathWorks, Inc., Natick, MA, USA). (1) ***Hue*** is the degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, or blue. Hue describes a dimension of color that is readily experienced (i.e., the dominant wavelength in the color). We calculated the average hue across all image pixels and the average standard deviation of hue across all of an image's pixels for each image. The average hue represents the hue level of the image and the (2) ***standard deviation of hue*** (SDhue) represents the degree of diversity in the image's hue[1]. (3) ***Saturation*** (Sat) is the degree of dominance of hue mixed in the color, or the ratio of the dominant wavelength to other wavelengths in the color. We calculated the average saturation of each image across all image pixels, as well as the (4) ***standard deviation of saturation*** for each image (SDsat). We also measured the overall darkness-to-lightness of a pixel's color depending on the brightness of the pixel. This dimension of color is called (5) ***Brightness*** (Bright) or the value of the color. We computed the average brightness of all pixels for each image, as well as the (6) ***standard deviation of brightness*** in each image (SDbright). **Figure 1** shows hue, saturation, and brightness maps of a sample image in our experiment, and **Figure 2** compares two images in terms of their color diversity (SDHue, SDSat, and SDbright).

[1]There was the concern that since high hue (hue = [0.92, 1]) and low hue (hue = [0, 0.05]) surfaces essentially have the same color at high enough brightness and saturation (Red), treating hue as a linear scale could result in incorrect representatives of average hue and SDhue values. To check this, we changed the high hue red pixels with brightness and saturation above 0.5 to zero hue and recalculated the Hue and SDhue variables. However, these recalculated variables were almost identical to previous ones ($R^2 = 0.999$ for both variables), hence no change was done to the analysis. The reason that SDhue and Hue are not dependent on the high hue red is that it happens with extremely low frequency in natural and urban photographic sceneries (On average, less than 0.01% of the pixels in our sample of images).

Spatial Properties

In this section we describe the spatial/structural features that were used in our analysis. A gray scale histogram of an image shows the distribution of intensity values of pixels that construct an image. Each pixel could have an intensity value of 0–255 (8-bit grayscale) and for a histogram with 256 bins, the probability value of the nth bin of the histogram (p_n) shows the number of pixels in the image that have an intensity value of n-1 over the total number of pixels in the image. (7) ***Entropy*** of a gray scale image is a statistical measure of randomness that can be used to characterize part of the texture of an image using the intensity histogram. We used a simple definition of Entropy:

$$Entropy = -\sum_{n=1}^{256} (p_n * \log_2 p_n) \quad (1)$$

Where p_n is the probability value of the nth bin of the histogram. Entropy shows the average "information" content of an image. The more the intensity histogram resembles a uniform distribution (all intensity values occur with the same probability in the image), the greater the entropy value becomes in the image. We calculated the entropy of the images as a measure of uncertainty or "information" content (versus redundancy) in the image's intensity values. More comprehensive and sophisticated definitions or variants of image entropy have previously been applied for natural images (for example, see Kersten, 1987;

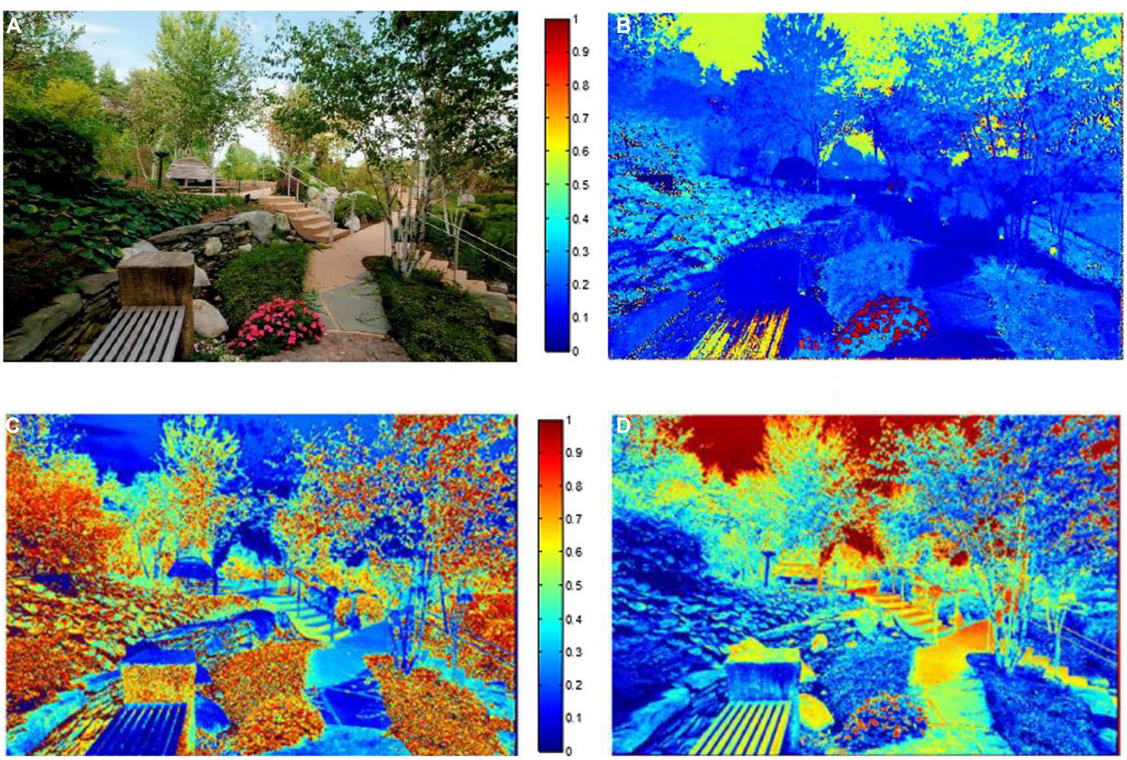


FIGURE 1 | (A) A sample image **(B)** Image's hue map **(C)** Image's saturation map **(D)** Image's brightness map. Pixels with hot colors have higher hue, saturation, and brightness in figures **B**, **C**, and **D**, respectively.

A

B

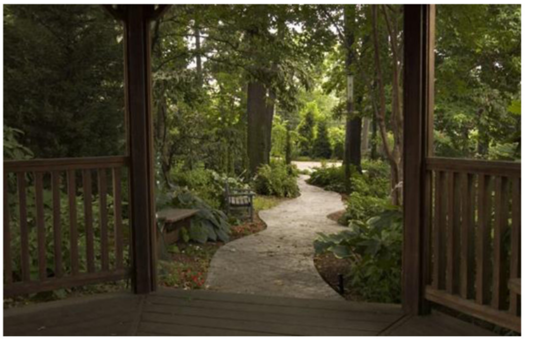


FIGURE 2 | Comparison of two images in their color diversity properties. (A) Example of an image with high variation in saturation and medium variations in hue and brightness. SDHue = 0.19, SDSat = 0.38, SDBright = 0.28. **(B)** Example of an image with low variation in saturation and hue and medium variation in brightness. SDHue = 0.05, SDSat = 0.16, SDBright = 0.15.

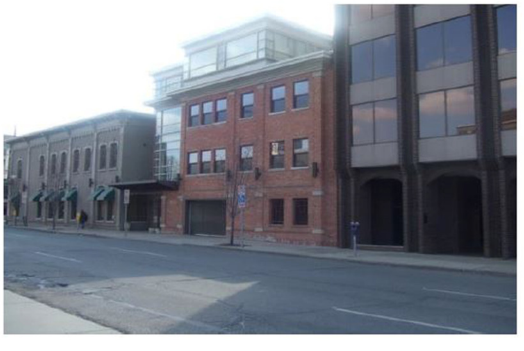
Field, 1999; Chandler and Field, 2007) that are not in the scope of this study, as we focused on more simple features that are less computationally demanding and have straight-forward interpretations. In addition, our chosen features could be readily manipulated in visual stimuli and built environments by designers, architects, urban planners, etc. **Figure 3** shows a comparison of high versus low entropy in two images.

Another image feature concerned the spatial or structural properties of images provided by image gradients. An image gradient is a map of the image's brightness intensity or color changes in a given direction. The points of discontinuity in brightness (rapid brightness or color changes) mainly consisted of object, surface, or scene boundaries, and fine details of texture in an image and are called *edges*. Images in this study (especially the more natural scenery) contain more complex detailed texture and fragmentations, which could lead to some complexities in edge detection.

The most commonly used method for edge detection is the Canny (1986) edge detection algorithm (see Klette and Zamperoni, 1996). This algorithm consists of five stages: first, blurring (or smoothing) an image with a Gaussian filter to reduce noise; second, finding the image gradients using derivatives of Gaussian operators; third, suppressing non-maximum gradient values; fourth, double thresholding weak and strong edges; and finally, edge tracking of weak or disconnected edges by hysteresis. This method is therefore less likely than the others to be influenced by noise, and more likely to detect true weak edges (see Canny, 1986). We used MATLAB's built in function "edge" and set the method to "canny" to calculate the pair of thresholds to be used by the canny edge-detection algorithm for each image. MATLAB uses a heuristic method to calculate a "reasonable" pair of lower and upper thresholds for the Canny algorithm when the thresholds are not specified. Then, the same function was used for each image with thresholds specified as 20% below (high sensitivity threshold) or 60% higher (low sensitivity threshold) than those determined by MATLAB[2]. This was done so that we could weight faint and salient edges differently, with each pixel potentially having a value of 0, 0.5, or 1

[2]For example if MATLAB suggested a [0.1, 0.2] threshold pair for an image, we fed 0.8*[0.1, 0.2] and 1.6*[0.1, 0.2] to the Canny edge detection for finding faint edges and salient edges of that image, respectively (see Gonzalez et al., 2004). Importantly, the modifiers 0.8 and 1.6 were determined heuristically by OK and MB by screening the calculated edge maps of images for a range of different modifiers. This procedure is the same as was used in Berman et al. (2014).

A



B

FIGURE 3 | Comparison of two images in their Entropy. (A) Example on an image with low entropy, Entropy = 6.92 **(B)** Example on an image with high entropy, Entropy = 7.76.

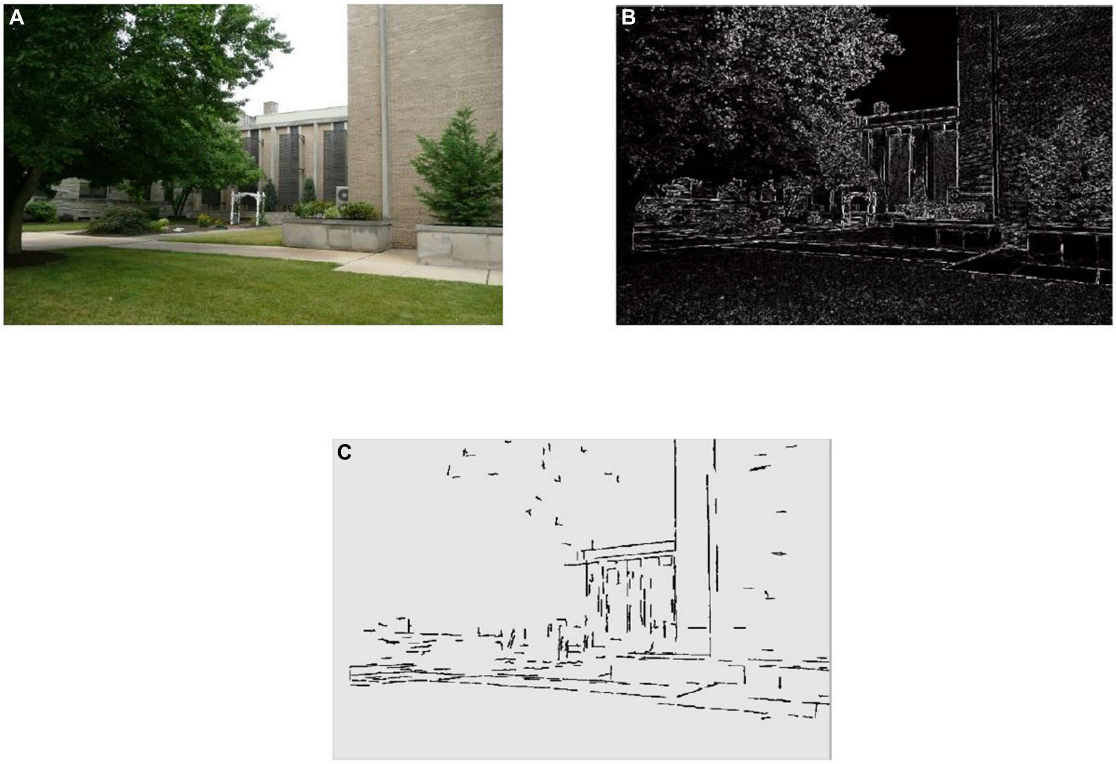


FIGURE 4 | (A) Sample image, **(B)** the edge density (ED) map of the sample image created from salient and faint edges of the image detected using Canny edge detection, and **(C)** the detected straight edges of the sample image used to calculate SED.

FIGURE 5 | Comparison of two images with different values of disorganized edge ratios: (A) Example of an image containing high ratio of non-straight edges relative to total ED, DER = 0.84 **(B)** Example of an image containing low ratio of non-straight edges relative to total ED, DER = 0.41.

depending on how sharp of an edge it belonged to. This was done in the following manner: pixels with a value of 0 were not identified as edges by the Canny edge detection algorithm at the high sensitivity threshold (i.e., pixels with a value of 1 were only detected as edges when using the high sensitivity threshold and not when using the less sensitive threshold (and therefore less salient edges); and pixels with a value of 2 were detected as edges with the lower sensitivity threshold and therefore were more salient. Finally, (**8**) ED was calculated for the image as the sum of total edge pixel values (i.e., 0 for non-edge pixels, 0.5 for faint edges, 1 for salient edges) over total number of pixels in the image.

Pixels belonging to straight edges (horizontal, vertical, and oblique lines) were also quantified so that SED and non-straight edge (curved or fragmented edges) density of images could be measured separately. Because of the complexity of the images, a typical Hough transform-based method could not detect straight lines accurately. Instead, we used a simple gradient-based connected component algorithm to detect straight lines in the images.

First, the images were convolved with the derivative of a Gaussian filter in the X and the Y directions to compute the gradient directions for Canny edges. Second, each edge was assigned to one of eight directions based on its value of $\tan^{-1}(G_y/G_x)$, where

G_y and G_x are the y and x gradients. Third, the connected components for the edge pixels in each direction were determined and labeled using MATLAB's 'bwconncomp' function. Finally, the Eigenvalues of the covariance matrix of the X and the Y coordinates of points for each connected component (edge) were used to compute the direction (the direction of the first principal component vector) and the straightness of the components. The first Principal component (PC) of the edge' coordinates should be parallel to edge's direction and the second PC captures the variability of edge's coordinates perpendicular to its direction. Pixels of a connected component above a threshold of straightness (the singular value for the first principle component more than 10^4 times larger than the singular value for second component) met the criterion of a "straight edge." The number of pixels on detected straight edges over total number of image pixels was calculated as (9) SED for each image. **Figure 4** shows a sample image with its edge and straight edge maps.

Lastly, in order to capture how many edges in an image consisted of curved or fragmented edges, the ratio of curved or fragmented edges (non-straight edges) density to total ED was calculated as a measure of (10) *Disorganized edge ratio* (DER) in each image. This measure captures part of the relatively more organized structure (greater in more man-made scenes) versus more chaotic or fragmented and non-straight edges (greater in more natural scenes) in the images, i.e., high DER indicates high disorganization. For example, **Figure 5** shows two images with high- and low-levels of DER, with their respective DER values included for comparison.

Results

Overview

In the results section, we first report the relationship of the quantified low-level image features with esthetic preference ratings using multiple regression. We then used our features to construct a model to predict naturalness based on the optimal linear combination of features. This was done by regressing naturalness ratings on the features and we did this to directly examine how modeled naturalness that is captured by bottom–up perceptions of naturalness relates to preference. Next, we confirmed the hypothesis that modeled naturalness is capturing bottom–up driven naturalness ratings. We did so by examining reaction times (RTs) when making preference judgments and found a positive relationship between RT and bottom–up naturalness (i.e., faster preference responses were more related to bottom–up naturalness), but the reverse relationship existed for non-modeled naturalness (i.e., slower preference responses were more related to non-modeled naturalness). Lastly, we assessed how naturalness modeled by structural visual features, naturalness modeled by color-related features, their interaction, and other aspects of naturalness that cannot be modeled with our features each uniquely contribute to esthetic judgment of scenes. In all of our analyses, we validated the generalizability of our models by utilizing a machine learning based classification analysis where we train a quadratic discriminant classifier to predict if an image was preferred by the participants.

Low-Level Image Features Predicting Preference

The correlation matrix of preference and image features shows significant zero-order correlations between preference and Hue, SDhue, SDsat, Entropy, ED, SED, and DER (see Supplementary Appendix). However, some of these features were correlated with each other, which complicates the interpretation of the zero-order correlations as a feature's correlation with preference may be confounded by another collinear feature. For example, SED is highly anti-correlated with DER as one would expect. Therefore, to assess the significance of each feature in predicting AP, we ran a regression of these features as variables in predicting preference. As can be seen in **Table 1**, low-level image features account for a significant proportion of variance in preference [adjusted $R^2 = 0.31$, $F(10,296) = 14.41$, $P < 0.05$]. This result is comparable to others in this area (e.g., about 25% of variance of image preference judgments captured by statistics like sparseness for art images: Graham et al., 2010). Standardized regression coefficients and their confidence intervals show that lower hue and more saturation diversity in the image predict more preference while a greater number of straight edges predicts lower preference. The confidence interval of DER suggests a marginal positive effect for DER as a predictor of preference when other features are adjusted for. In fact, if we remove SED from the analysis, higher DER becomes strong predictor of preference, which is due to its high degree of shared variance with SED as mentioned before. In summary, some objective low-level features significantly predicted subjective preference judgments.

Naturalness Ratings Predicting Preference

We also examined how perceptions of naturalness could predict preference. As one might expect, the naturalness of the image strongly predicted its preference, $R^2 = 0.52$, $F(1,305) = 340$, $P < 0.05$, confidence interval = [0.66, 0.82]. This result indicates that images of natural scenes are more preferred than scenes with more man-made content. This is an expected result and replicates previous work by Kaplan et al. (1972).

TABLE 1 | Results of regressing esthetic preference on image features.

Predictor	Estimate	SE	*t* value	CI
Edge density	0.008	0.066	0.128	[−0.120 0.137]
Straight edge density*	−0.382	0.064	−5.924	[−0.509 −0.255]
Hue*	−0.177	0.061	−2.888	[−0.297 −0.056]
Saturation	−0.089	0.079	−1.125	[−0.244 0.066]
Brightness	0.085	0.051	1.66	[−0.015 0.185]
SDhue	−0.009	0.066	−0.139	[−0.140 0.121]
SDsat*	0.214	0.069	3.096	[0.078 0.350]
SDbright	−0.031	0.054	−0.565	[−0.137 0.076]
Entropy	0.066	0.062	1.064	[−0.056 0.188]
Disorganized edge ratio	0.123	0.065	1.884	[−0.005 0.251]

*Adjusted $R^2 = 0.31$, $F(10,296) = 14.41$, *$P < 0.05$.*

Low-Level Image Features and 'Bottom–Up' Perceptions of Naturalness

Next, in order to examine how preference is related to the variance of naturalness that is predicted by the low-level visual features versus the aspects of naturalness that is not captured by these features, we regressed naturalness on the visual features. The results of this regression are shown in **Table 2**. Replicating findings of Berman et al. (2014), these features explain a substantial amount of variance in naturalness ratings [$R^2 = 0.54$, $F(10,296) = 36.73$].

We used the regression equation of naturalness = 3.573 −0.249**Hue* −0.220**SDhue* −0.756**Sat* +0.244**SDsat* +0.069**Brightness* −0.059**SDBright* −0.021**Entropy* +0.717**ED* −0.299**SED* +0.582**DER* +e as our linear model to calculate the predicted naturalness score (modeled naturalness) and its deviation from the naturalness rating (non-modeled naturalness) for each image. This way we could assess the degree to which preference of images is related to bottom–up naturalness that is captured by the visual features, assuming that naturalness that is predicted by this model is actually related to bottom–up perception of naturalness. This requires that the visual features capture most (almost exhaustively) of low-level visual information.

The Effect of Bottom–Up Perception on Judgments of Naturalness

After separating naturalness ratings into modeled and non-modeled naturalness based on the low-level visual features, we hypothesized that if modeled naturalness is truly related to bottom–up processing (i.e., processing that is driven more by the stimulus features) of naturalness of an image, its effect on preference should emerge for faster preference ratings (i.e., faster RTs) since bottom–up processing tends to be a faster and more automatic process (Kinchla and Wolfe, 1979; Theeuwes et al., 2000; Delorme et al., 2004). This was tested by analyzing the interaction of modeled and non-modeled naturalness with the time to make a preference judgment (i.e., the RT for making a preference judgment) in predicting preference ratings for the images. RT for each image was the calculated average RT from each participant's rating of preference from each image. RTs were *z*-scored within subjects to account for individual differences in the speed of preference judgments before being averaged over participants.

Table 3 shows the results of the regression of preference on the interaction of preference RT with modeled naturalness (i.e., bottom–up perceptions of naturalness). As can be seen in the table, more naturalness captured by features strongly predicts more preference, i.e., images with more modeled naturalness are preferred over images of high modeled urbanness (the main effect). Importantly, the relationship of modeled naturalness with preference decreases as the RT of preference judgment increases in the images (the interaction). This suggests that when preference judgments are made quickly, those judgments are more reliant on the visual features of the images that drive naturalness ratings. Therefore, images that are more natural in a way that is predictable by this model are also rated more quickly by the participants. On the other hand, images that are more natural in a way that our model fails to predict (higher non-modeled naturalness) are the ones that are also rated slower and more deliberately by the participants. This is suggested by **Table 4** that shows the results of the regression of preference on the interaction of RTs with non-modeled naturalness.

To illustrate this double dissociation better, we plotted the relationship between preference and modeled and non-modeled naturalness from **Tables 3** and **4** in **Figure 6**. Blue lines show regression lines relating preference to modeled naturalness (left) and non-modeled naturalness (right) when the RT of preference judgments are at the average RT. Red and black lines show regression lines relating preference to modeled naturalness (left) and non-modeled naturalness (right) when the RT of preference judgments are slow (mean + 1.5 SD), and fast (mean − 1.5 SD), respectively. As can be seen in the figures, modeled naturalness becomes a better predictor of preference in faster judgments (black line is steeper then red line in the left figure), whereas non-modeled naturalness becomes a better predictor of preference in slower judgments (red line is steeper then black line in the right

TABLE 2 | Results of regressing perceived naturalness on image features.

Predictor	Estimate	SE	*t* value	CI
(Intercept)*	3.573	0.07071	50.53	[3.434 3.712]
Edge density*	0.717	0.130	5.479	[0.459 0.974]
Straight edge density	−0.299	0.174	−1.713	[−0.643 0.044]
Hue*	−0.249	0.091	−2.735	[−0.429 −0.069]
Saturation*	−0.756	0.125	−6.028	[−1.004 −0.509]
Brightness	0.069	0.074	0.929	[−0.077 0.215]
SDhue*	−0.220	0.094	−2.332	[−0.406 −0.034]
SDsat*	0.244	0.099	2.462	[0.049 0.440]
SDbright	0.059	0.082	0.720	[−0.102 0.220]
Entropy	−0.021	0.085	−0.256	[−0.190 0.146]
Disorganized edge ratio*	0.582	0.164	3.534	[0.257 0.906]

*Adjusted $R^2 = 0.54$, $F(10,296) = 36.73$, *$P < 0.05$.*

TABLE 3 | Results of the regression of esthetic preference on modeled perceived naturalness, RT, and their interaction.

Predictor	Estimate	SE	*t* value	CI
Modeled naturalness*	0.453	0.051	8.896	[0.353 0.554]
Reaction time (RT)	−0.036	0.048	−0.752	[−0.131 0.058]
RT X modeled-naturalness*	−0.247	0.048	−5.141	[−0.341 −0.152]

*RT is Reaction Time, RT X modeled naturalness is the interaction term. Adjusted $R^2 = 0.34$, $F(3,303) = 54.23$, *$P < 0.05$.*

TABLE 4 | Results of the regression of esthetic preference on non-modeled perceived naturalness, RT, and their interaction.

Predictor	Estimate	SE	*t* value	CI
Non-modeled naturalness*	0.482	0.051	9.505	[0.382 0.582]
Reaction time	0.069	0.052	1.338	[−0.033 0.171]
RT X non-modeled naturalness*	0.108	0.048	2.248	[0.014 0.202]

*RT is reaction time, RT X non-modeled naturalness is the interaction term. Adjusted $R^2 = 0.25$, $F(3,303) = 35.01$, *$P < 0.05$.*

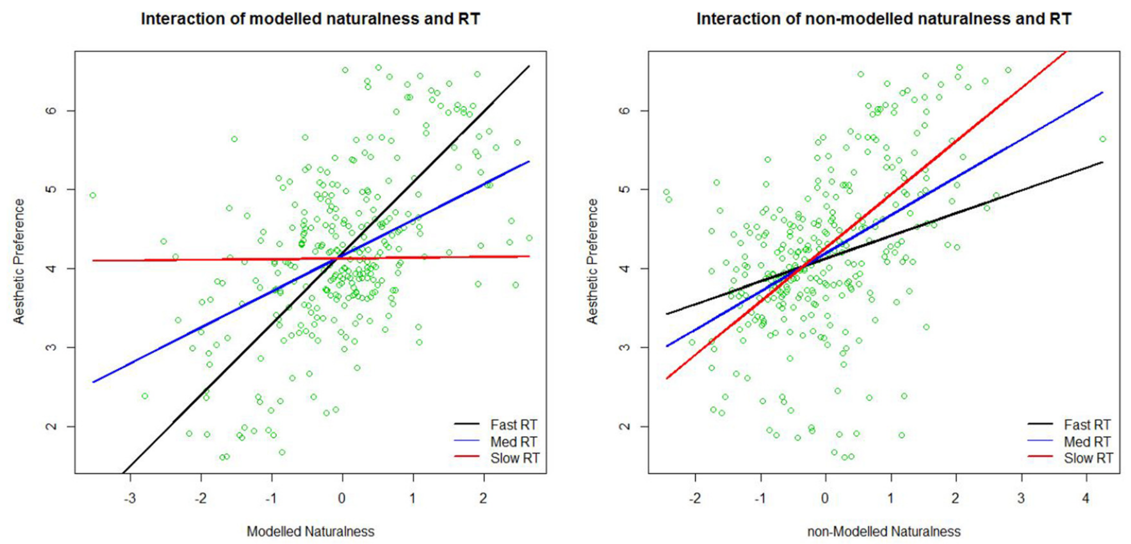


FIGURE 6 | Plots of the interaction of modeled naturalness and the reaction time (RT) to make the preference judgment (left) in predicting preference ratings, and the interaction of non-modeled naturalness and the RT to make the preference judgment (right) in predicting preference. Lines show fitted regression lines of preference regressed on modeled naturalness **(left)** and non-modeled naturalness **(right)** at three different levels of RT. Med RT is at the mean RT and Fast and Slow RT are at mean RT ± 1.5*SD of RT.

figure). Therefore, we can claim that our features are modeling the more bottom–up aspects of naturalness important for esthetic judgment and the part of naturalness in the images that is not predictable by them is probably less related to bottom–up perception of nature. Whether the non-modeled aspects are associated with top–down perception of naturalness is beyond the scope of our data.

Edge- and Color-Related Aspects of Naturalness in Predicting Preference

To isolate specific effects of color and structure, modeled naturalness was further decomposed to Naturalness-color (predicted naturalness based on only our six color features), and Naturalness-structure (predicted naturalness based on only our four spatial features), and also the interaction of these two components. **Table 5** shows the results of regression of preference on these two components and their interaction, as well as the non-modeled naturalness predictor.

Our results suggest that people like both color-related regularities (less average hue and more diversity in saturation) and structure-related regularities (less straight edges and more disorganized edges), which tend to be more common in more natural scenes. Importantly, these features are more important in faster preference judgments. Additionally, the preference for these color-related and structure-related properties in an image increases preference not additively, but in an interactive way. Almost as important, people prefer the semantic idea of nature versus more man-made semantics, which may be captured by non-modeled naturalness (i.e., naturalness various that was not predicted by the low-level visual features).

TABLE 5 | Results of regressing esthetic preference on color-related and structure-related bottom–up naturalness and non-modeled naturalness.

Predictor	Estimate	SE	*t* value	CI
Modeled-naturalness-color*	0.362	0.081	4.454	[0.202 0.521]
Modeled-naturalness-structure*	0.533	0.055	9.629	[0.424 0.642]
Non-modeled naturalness*	0.480	0.043	11.164	[0.396 0.565]
Color X structure*	0.207	0.092	2.237	[0.025 0.389]

Color X structure is the interaction between modeled-naturalness-color and modeled-naturalness-structure. Adjusted $R^2 = 0.47$, $F(4,302) = 69.36$, $*P < 0.05$.

Quadratic Discriminant Classification of Esthetic Preference

To further assess the reliability/reproducibility of features and naturalness in predicting preference we performed a multivariate machine-learning classification analysis to predict preference. The classifier we chose was a quadratic discriminant (QD) algorithm, which has been implemented with great success to classify brain states and participants' brain activity patterns (Yourganov et al., 2010, 2014; Berman et al., 2013). This classification analysis provides complementary information to the regression results as this classification analysis speaks directly to the reproducibility of the results and not just the effect-sizes. Also, because the classifier is non-linear and distinguishes classes with a non-linear surface, it provides additional information that is absent in a linear regression model.

We trained a multivariate machine-learning algorithm, the quadratic discriminant classifier, utilizing the low-level visual features to predict the preference of the images. Utilizing a leave-one-out cross-validation framework we could test how well the quadratic discriminant classifier could accurately predict the preference of the image.

TABLE 6 | Results of quadratic discriminant classification of esthetic preference for images using different variables.

Variable(s) in classification	Prediction accuracy
Image features	69.2%
Modeled naturalness	61.9%
Non-modeled naturalness	66.9%
Modeled + non-modeled naturalness	70.9%
Image features + non-modeled naturalness	78.8%

Implementation of QD classification was performed using the classify function in the Statistics toolbox in Matlab (the classifier type was set to 'quadratic'). The QD classifier uses a multivariate Gaussian distribution to model the classes and classify a vector by assigning it to the most probable class. The QD model contains no assumption of homoscedasticity, and instead estimates the covariance matrices separately for each class (that is, the variances of and the correlations between features are allowed to differ across high versus low-preferred images). This indicates that when implementing QD the two classes are separated by a non-linear curved surface.

We evaluated the success of the classifier using a cross-validation approach. A subset of images was used to train the classifier, and the image type based on a median split on AP (high preference versus low preference) was predicted for the images that were not included in the training set. At each iteration, two images (one high-preferred and one low-preferred) were held out for testing, and the remaining 305 were used to train the classifier; this process was repeated so that all combinations of high and low preferred images were determined by classification.

Results of QD Classification of Preferred versus Not Preferred Images

For each combination of left-out high- and low-preferred images we computed whether the image type was predicted accurately. The proportion of images that were accurately predicted was our metric of *prediction accuracy*, our main measure of the efficacy of the classifier. We first introduced all 10 features for classification, and then excluded feature that dropped the classification accuracy. Our logic in the classification was to get maximum accuracy by omitting features that are redundant[3]. **Table 6** shows the prediction accuracy of the QD classifier using features only (Hue, Saturation, SDhue, SDsat, Entropy, SED, and DER (69.2%), using the modeled naturalness values only (61.9%), using the non-modeled naturalness only (66.9%), using modeled and non-modeled naturalness together (70.9%), and using features (Hue, Saturation, SDhue, SDsat, Entropy, SED, and DER) and non-modeled naturalness together (78.8%). In all cases chance is at 50% and also classification was above chance. This classification analysis demonstrates that features and semantics are each uniquely important and are reliable predictors of preference. The fact that features predict preference better than modeled naturalness shows some features are predictors of preference independent of their relationship to the perceived naturalness of the scenes.

[3]The Classifier worked best with these features. Adding Brightness, SDbright and ED decreased classification accuracy. The fact that ED becomes redundant in classification analysis is probably because DER and SED and their quadratic and multiplicative terms capture all the information of ED.

Discussion

We quantified the spatial structure and the color properties of a corpus of images with a spectrum of man-made and nature content by decomposing images that were rated on subjective preference and naturalness. Results from multiple regressions of preference on these low-level features showed that some of these features could significantly predict esthetic preference of the images and accounted for a large portion of the variance in preference. Specifically, lower SED (more non-straight surfaces, borders, and shades), lower hue level (lower hue means more yellow-green content rather than blue-purple content), as well as higher diversity in saturation (scene containing both low and highly saturated colors) predicted more preference, adjusting for the other visual features. In addition, and our linear model explained 31% of variance in preference ratings.

We also showed that individuals prefer scenes that are labeled as more natural. However, some of the image features predict preference above and beyond the semantic category of the images. In a relatively similar but more limited study, Kaplan et al. (1972) inspected how perceived complexity (rated by the subjects) and the content of images (natural versus urban) influenced esthetic preference of slides of nature and urban scenes. They found that nature scenes were greatly preferred to urban scenes and that complexity rated by participants (perhaps related to DER in this study) predicted preference within the natural and urban domains, but did not account for the preference for nature over urban slides.

Next, we used a linear regression and modeled naturalness by predicting it using visual regularities we found in the scenes rated as natural versus urban. These included higher ED and higher proportion of curved and fragmented edges, lower hue and saturation, less variation in hue levels, as well as more variations in saturation of colors. Using the estimates from our model of naturalness, we extracted the aspect of subjective naturalness that can be modeled by these visual characteristics. By introducing RTs of participants' esthetic ratings on images into our analysis, this modeled naturalness was then shown to be a better predictor of esthetic judgments that are made faster and less predictive of preference in slow ratings.

After removing the low-level visual regularities of natural scenes, the remaining aspect of perceived naturalness is less likely to be correlated with bottom–up processing of preference as our analysis of RTs' interaction with non-modeled naturalness showed that non-modeled naturalness becomes more predictive in more delayed preference judgments. This suggests that the other factors that affect naturalness judgments and are not modeled by our features, such as experience and semantic knowledge, may affect one's judgment more deliberately and slowly. However, making firm conclusions about this is beyond the scope of our data.

One important question is why some of the visual features relate to perceived naturalness or esthetic preference and others do not? While we do not have empirical evidence to directly answer this question, we believe that some of the statistical regularities in natural and urban environments, which were uncovered here, make intuitive sense in terms of predicting naturalness. For example, shrubbery, trees, waterfalls, rocks and bodies of water have more yellow/green colors and also more defragmented or curvy surfaces compared to brick walls, streets, cars, fences, etc. Additionally, the variations in color saturation levels in a brown hillside are greater than that of a brown painted wall. These properties are in line with lower hue, higher ED, higher DER, less straight edges, and more SD in saturation; all of which were related to preference. In relation to previous work, fewer straight edges (or more non-straight edges) in a scene can lead to more complexity or more chaotic patterns that Kaplan et al. (1972) and Aks and Sprott (1996) previously associated with preference in scenes and visual patterns, respectively. In summary, we believe the features that were related to preference make sense from an intuitive perspective and also match with previous literature results. However, more empirical testing will be needed to understand the mechanisms behind preferences for these features.

The fact that predictable bottom–up perceptions of naturalness were related to preference suggests a few testable hypotheses in terms of which environments may be most restorative according to ART. ART claims that natural environments are restorative because they tend to place few demands on top–down directed attention, while simultaneously capturing bottom–up involuntary attention processes via soft fascination (i.e., modest attentional capture; Kaplan, 1995; Berman et al., 2008; Kaplan and Berman, 2010). By this rationale, it is possible that environments whose preference was determined more so by modeled naturalness (from the low-level visual features) may be more restorative than environments whose preference was determined more so by aspects of naturalness that could not be modeled with the low-level visual features. It could be theorized that images containing higher values of predictable (bottom–up) naturalness may be less taxing of top–down attentional mechanisms and thus more "softly fascinating." For instance does interacting with man-made environments that resemble nature in these visual characteristics (for example fractal curves in architecture, using yellow–green colors with high saturation diversity in building facades, etc.) bring about some restorative effects of nature? Is naturalness that is more predictable also more effective in restoration than natural content that is not liked as fast and less predictable? These are all testable hypotheses that could help to inform ART and other theories of why interacting with nature is beneficial.

Fifty of the nature scenes that we used in this study have previously been shown to improve attentional resources and memory performance (Berman et al., 2008). The results we found here pave the way for our future work, which will focus on how the features we analyzed here might correlate with the attentional and memory benefits of viewing natural scenes, and how we might further inspect the driving low-level features that make interacting with nature restorative. Here too it will be important to separate the effects of the low-level features from that of the semantics (i.e., is it the low-level features that may improve cognitive performance or simply the very idea of nature that would improve performance).

It is important to emphasize again that restoration does not happen as a result of improvement in the mood by interacting with nature. In our previous work, we have found no relationship between improvements in mood and changes in memory and attention performance (Berman et al., 2008, 2012), indicating that participants do not need to enjoy the nature interaction to obtain the cognitive benefits. While mood and preference may not drive the cognitive benefits that are gleaned from interacting with nature, preference and mood may be driving motivational variables that would inspire one to interact with a natural environment. Here we have identified low-level image features that may increase this preference as well as the perceived naturalness of the environment. Our features are relatively easy to quantify and manipulate and have straight-forward interpretations for urban environment designers, architects, and planners. These features may motivate one to interact with an environment that could benefit them cognitively, and future work is aimed to determine whether these same features also act to improve cognitive performance directly, even when semantics are removed from the scenes.

Conclusion

In this study, we aimed to explore whether the preference of natural versus man-made scenes is driven by the bottom-up processing of the low-level visual features of nature. We used 10 low-level visual features to predict esthetic preference in images containing a spectrum of urban to natural content. Our model successfully explained 31% of the variance in preference ratings. We also used these features to decompose the perceived naturalness of each image to its predictable (54% of variance modelled by the features) and non-modelled aspects and showed that bottom-up perceptions of naturalness (modelled by the image features) related more to preference when the preference judgment was faster (i.e., a shorter reaction time to make the preference rating). We also found that color-related and edge-related characteristics of nature interactively contribute to preferring one scene over another. Finally, to validate the generalizability of our models, we utilized a machine-learning classification analysis and were able to successfully train a classifier to distinguish liked (above median preference) and disliked (below median preference) images with almost 70% accuracy based solely on their visual features. Our results lend to the possibility that there may be low-level visual regularities of natural environments that we are "programmed" to gain benefits from (esthetic pleasure among others). Our findings have theoretical importance in determining why nature may be cognitively beneficial and may also have practical importance as these results could be used in the design of built environments to improve psychological functioning. Future studies may involve assessing the direct bottom-up effect of these features on the restorativeness of environments by manipulating these features in semantic-free visual stimuli.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.00471/abstract

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Designer's approach for scene selection in tests of preference and restoration along a continuum of natural to manmade environments

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It is well-established that the experience of nature produces an array of positive benefits to mental well-being. Much less is known about the specific attributes of green space which produce these effects. In the absence of translational research that links theory with application, it is challenging to design urban green space for its greatest restorative potential. This translational research provides a method for identifying which specific physical attributes of an environmental setting are most likely to influence preference and restoration responses. Attribute identification was based on a triangulation process invoking environmental psychology and aesthetics theories, principles of design founded in mathematics and aesthetics, and empirical research on the role of specific physical attributes of the environment in preference or restoration responses. From this integration emerged a list of physical attributes defining aspects of spatial structure and environmental content found to be most relevant to the perceptions involved with preference and restoration. The physical attribute list offers a starting point for deciphering which scene stimuli dominate or collaborate in preference and restoration responses. To support this, functional definitions and metrics—efficient methods for attribute quantification are presented. Use of these research products and the process for defining place-based metrics can provide (a) greater control in the selection and interpretation of the scenes/images used in tests of preference and restoration and (b) an expanded evidence base for well-being designers of the built environment.

Keywords: preference, restoration, well-being, environmental structure, evidence-based design, restorative urban spaces, psychological ecosystem services, design aesthetics

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Introduction

Over the past 50 years, environmental psychology research has made predictions about the mechanisms and outcomes of human response to the environment. Empirical research has shown repeatedly that people prefer and are restored by environments with nature or nature elements in evidence (reviewed in Velarde et al., 2007; Bratman et al., 2012; Ryan et al., 2014). Much less is known about the specific attributes of green space which produce these effects. In the absence of translational research that links theory with application, it is challenging to design urban green space for its greatest restorative potential. This paper describes an approach for defining which physical components, spatial characteristics, and collective arrangements of nature best meet theoretical predictions about preference and restoration in outdoor environments.

There has been some research on the impact of multiple physical attributes on preference or restoration. The importance of combinatorial effects in the environment has been noted by Berlyne (1970) who proposed that environmental scenes include collative properties, characteristics that cause a viewer to pay attention–Engagement, investigate further–Information Gathering, and compare. He predicted that when all of the collative properties occur in moderation, the viewer will perceive the setting as more beautiful. Ulrich (1983) offered support for this premise in his review of empirical work on aesthetic preference for specific visual properties of environment. With this data he considered the role of eight attributes (all but two were structure attributes) and was able to infer which character states in which combinations should be most preferred. Ryan et al. (2014) took a similar approach and were able to infer which specific physical attributes (design parameters) support Biophilia, people's need to connect with the natural world. Ewing and Handy (2009) used a different approach to decipher urban environmental complexity. Using an expert's panel, physical characteristics of streets, and their edges that best represented eight urban design properties (e.g., imageability and transparency) were identified.

Such research outcomes can serve as the premise of evidence-based design, a process that translates research outcomes for creation of the built environment, be that new development, restoration, or conservation (Hunter and Hunter, 2008). Here is an example of how the process could work for the design of restorative spaces. Ulrich (1983) noted that humans perceive nature stimuli as visual arrays more than individual objects and that we are strongly engaged by information that includes redundant elements, groupings of elements, patterns established by homogeneous texture, and properties that bring continuity to separated or dissimilar elements. Here, is a typical urban example that satisfies all criteria and does so with nature elements. Consider the view down a street that is symmetrically flanked by street trees planted at regular intervals. Since the early sixteenth century, roadways and promenades have used this structural format (an *allée*) to great effect (Pradines, 2012). Gestalt theory predicts that the structural/organizational properties of the whole will influence aesthetic preference. With an allée, trees provide the main lines of sight, guiding the eye toward a chosen focal point, often a vista (defined by the sky, horizon line, and land beyond), a perspective that opens into infinity. The content and structural form of this oft repeated form is known to be engaging, and even transcendent, depending on the chosen focal point (e.g., the sky). The success of the allée can be explained in terms of longstanding design principles as well as theories about survival, success, and aesthetic pleasure.

In this time of global urban densification, designers of the built environment are in need of a broader evidence base about which content and structure (spatial configuration) attributes offer the best chance to support restoration and well-being. Currently, the most common solution is to emulate natural scene aesthetics. This is not sufficiently prescriptive to meet the challenge of shrinking available space for greening. Designers are already well aware that preferred urban spaces are those with plants and water, attractive framing of good views, screening of buildings and roads, and presence of the disappearing curved path into vegetation, these being based on design principles that have been functional for centuries if not millennia (Jellicoe, 1995), and they continue to be taught today. What is most needed is better information about which physical components of a scene, acting alone or contextually, are involved in preference and restoration responses to urban nature.

Landscape designers use longstanding design principles to support the creation of settings that meet aesthetic, environmental and land use goals of a project. They also routinely apply research outcomes from the fields of ecology and engineering to meet environmental regulations and sustainability goals. The embrace of environmental psychology research outcomes has been limited for two reasons: there are few directives beyond "green is better, manmade is bad" that transcend what is already provided by design principles and aesthetics theory. Here, we describe an approach to help crack that generalization with a list of measureable, physical attributes (*aka* design components) that can be tested for their ability to support human well-being and better provide psychological ecosystems services in urban areas.

This study describes an approach to identify specific and measureable physical attributes of an environmental setting that are most likely to influence preference and restoration responses. The approach is practical, efficient, and founded in theory and existing empirical research. The process begins with a search for commonly invoked properties of spatial structure and content in theory predictions from the fields of environmental psychology, aesthetics, and design. This is followed by discovery process to identify specific physical attributes of the environment that fulfill four exacting criteria, including the ability to be measured.

Methods

The sequential process described below allowed us to weave interdisciplinary considerations from several fields to identify physical attributes of nature most likely to generate preference and restoration responses.

(1) Set the criteria for which theories to consider. We chose among theories from the fields of environmental psychology and environmental aesthetics that include predictions about human preference for nature and/or restoration from exposure to it. We also considered design principles, historically-embraced in the fields of art and design. These principles are founded in the generation of form and space thought to be in keeping with the harmony of the universe and human aesthetic response. Design principles offer rich insight about how spatial configurations of content are perceived and which configurations are most engaging or restorative.

(2) Identify structure-content properties based on commonly held predictions about preference and restoration among the selected theories. Theory predictions were sorted into topically-related categories (structure-content properties), each of which was named with an encompassing descriptor.

(3) Identify specific physical traits (attributes) most likely to be involved in the expression of shared predictors of preference and restoration (structure-content properties). Inclusion of a physical attribute required that four criteria be satisfied: (1) alignment with theory-based shared properties; (2) alignment with formal design principles and/or empirical evidence or logical support for the relation of an attribute to preference or restoration; (3) ability to be measured objectively, and (4) capacity to be readily constructed, controlled or conserved by designers charged with the task of creating preferred and restorative outdoor spaces.

Our discovery process of appropriate attributes made use of the design process, an approach to investigation and product development used universally by landscape architects and architects. The design process works iteratively among the following tasks: gathering information (including evidence-base offerings from research where available), analyzing information relative to the project goal, and design creation using logic, intuition, creativity, visual communication, and testing for intended function.

(4) Ensure that attributes can be reliably measured. Since attributes are to serve as a set of testable hypotheses about which specific physical attributes of outdoor settings contribute to preference or restoration responses, there must be a measurement method that is readily used by other researchers. The metrics of each attribute were defined and adjusted throughout the discovery process until they were fully functional–meaning that the character states were easily understood, efficiently measured, and collectively encompassed the range of possible outcomes.

Throughout the process of attribute definition, one discussion was recurrent—how to readily measure 3D features of the outdoor environment using 2D representation (e.g., photos). This focus also helped avoid the problem of picking physical attributes that would be impossible to assess from images owing to unfounded assumptions (e.g., about what lies beyond the frame of view). Examples of attributes with good objectivity include horizon line position, perspective view, and the ever popular % green vegetation.

A key part of the iterative design process was testing the clarity of attribute metrics. This was done with 400 images collected from participants in another research project who had been charged with taking pictures of scenes that produced a positive reaction during a nature experience. Since compositional quality (e.g., presence of a focal point, balance, or unity) can make all the difference in response of a test subject to a scene, the use of this image source ensured that the method of scene analysis that was not dependent on the quality of the photo.

Attribute definitions and metrics (verbal and graphical) were adjusted and retested using images never before seen by scorers until consensus was reached. Throughout this process, three trained scorers worked independently then compared results. Where discrepancy occurred, a 4th scorer was consulted, followed by group discussion and decision about what adjustment to make.

For most attributes, convergence was 100% by the end of the definition/metric building process. For several attributes, convergence was not achieved 2–4% of the time and group discussion and decision was still required; use of an outside scorer was valuable in such cases.

For attributes defined terms of area, the perimeter was outlined in Photoshop and data were processed in Grasshopper with a program developed to efficiently make area calculations. Area occupied by an attribute was calculated as the percent of an image's total area, allowing measurements to be calibrated for comparison.

Results

Theories Chosen for Consideration

Theories about human response to nature predict that a preferred or beneficial setting is one that offers protection, supports resource acquisition and, if survival-reproduction needs are met, provides opportunities for adventure or transcendence. Predictions from the following theories were used as the basis for identifying physical attributes of a scene or image that activate preference or restoration responses.

The first three theories are evolutionary in essence, focusing preference responses to environmental stimuli that are innate, an outcome of natural selection for survival and fitness. Evolutionary aspects of environmental preference posit that scenes offering the resources and opportunities necessary for success will elicit a positive aesthetic reaction (e.g., pleasurable) and have come to be preferred on that basis. Biophilia (BT) predicts the urge to affiliate with the natural world and its diversity, particularly, the diversity of landscapes, habitats, and species (Wilson, 1984). Habitat/Prospect-Refuge theory (PRT) predicts that human experience of pleasure and satisfaction is associated with landscapes that meet biological needs for survival and success. Even in the absence of imminent danger or need, the positive aesthetic response to valued or formerly valued landscapes will occur (Appleton, 1975). More specifically, Prospect-Refuge predicts a preference for places that offer outlook, enclosure, and aesthetic pleasure. Savanna theory (ST), a corollary of Prospect-Refuge theory, predicts a preference for places with the spatial form of the savanna habitat where critical phases of human evolution occurred. Savanna form is typified by open grassland for prospect and intermittent climbable trees for refuge (Orians and Heerwagen, 1992).

The next three theories variably address the roles of affect and cognition in landscape preference and restoration without precluding innate response. Stress Recovery theory (SRT) (Ulrich, 1983; Ulrich et al., 1991) predicts an improvement in emotional and physiological states in response to a non-threatening nature experience, all of this mediated by the initial affective state of the individual. A preference response to a setting is initiated by an affective aesthetic reaction which is in part hardwired, the outcome of natural selection for survival and success. More specifically, Ulrich (1983) predicts that natural scene preferences will be related to aspects of a setting's visual properties in terms of structure, organization, and general content classes such as water or man-made components that support survival and success. Environmental Information Processing theory (EIPT) predicts preference for landscapes that facilitate information gathering and support the capacity to plan for the purpose of survival, success, and further exploration. Preference is based on information processing of what is directly observed of a landscape's coherence and complexity along with what is inferred about its legibility and mystery (Kaplan, 1987). Attention Restoration theory (ART) predicts that the experience of nature restores the capacity for directed attention when nature is configured to create the sense of being away from everyday thoughts and concerns; to provide fascination defined as effortless attention; to offer sufficient content and structure to occupy the mind long enough for one's directed attention to rest; and to have a compatibility between one's purposes and what the environment offers. Interpretation of a scene can involve desires, memory, and experience, although innate response can transcend the personal details of why a setting is suitable (Kaplan and Kaplan, 1989; Kaplan, 1995).

The next theories focus on the role of aesthetic response in landscape preference and restoration responses. These offer a useful stepping stone for operationalizing environmental psychology predictions because they are more specifically focused on physical elements of landscape design. Environmental Aesthetics theory (EA) joins physical and emotional criteria used in the world of art to define aesthetic response in terms of meaningful outcomes ranging from survival to transcendence (Carlson, 2015). Environmental Aesthetics via Urban Design (EA-Urban) makes predictions about the attributes of a successful city. The emphasis is on built structures, nature elements being left primarily as modifiers. Nonetheless, understanding which forms and spatial configurations are preferred and restoring is of interest because most people live in urban settings worldwide. Where there is limited space for nature in the city, it is critical to know which built content, configured in what ways, including how much nature will be preferred and most supportive of restoration. The works of Lynch and Ewing are useful here because they deal with aspects of design that transcend which materials are employed–natural, man-made or man-made emulating nature. Lynch's (1960) *Cognitive Mapping* identifies and makes predictions about five elements that support wayfinding which make the landscape comprehensible and useful. Ewing et al. (2006) proposed that *Walkability* could be better integrated with city design by evaluating the design in terms of nine urban design qualities, many of which were put forth by Lynch (1960).

A Pattern Language*: Towns, Buildings, Construction* (Alexander et al., 1977) is guide to urban design, organized as a hierarchical network of interrelated design solutions that lead to desirable built spaces. This book offers a set of hypotheses in the form of 253 "patterns" each of which describes a problem about the spatial configuration and context of communities, streets, or buildings that influence the quality of life. Each problem is paired with a set of design solutions to improve the aesthetic experience and human well-being. The validity of both problem and solution is based on the history of successful built spaces, empirical research outcomes, and the design and construction experience of the authors. The book is aimed at urban planners and architects but is included here because both problem and solution often disclose specific physical attributes of three dimensional space that influence preference and restoration.

Scenic and Landscape Aesthetics theories (S-LA) are distinct from Environmental Aesthetics in their approach for evaluating the scenic quality of landscapes which often includes valuation of ecological function (USDA-FS, 1995). The goal is to produce criteria for landscape conservation and development that provides, saves, and frames beautiful views as the viewer moves through a larger scaled landscape such as a public park or along a highway. It is included here as it is based on psychophysical criteria about preferred views (scenic beauty) for viewshed management of large scale landscapes. And it employs measurable landscape characteristics (Daniel and Boster, 1976).

Design Theory–Formalized Principles (DP) Formal design principles have emerged over millennia. Many principles are based in mathematics and the long held belief that numerical relationships manifest the harmonic structure of the universe (Ching, 2007) and, by extension, will be preferred and in some way restorative. Design principles are the vocabulary for creating an object, a setting, or a series of settings where form and space are ordered to bring unity, balance, and a spatial or temporal hierarchy to the whole. These characteristics play a key role in aesthetic response. Visual engagement and interpretation is founded on the arrangement of lines, forms, and their sensory attributes (like color and texture) in terms of proportion, scale, and ordering principles such as symmetry and rhythm. The body of knowledge summarized in design principles continues to be used worldwide by design professionals and artists.

Many formal design principles like the golden mean and the location of a horizon line) are foundational for the digital field of visual aesthetics (e.g., Bhattacharya et al., 2010). It is not a surprise that many of the design principles for preferred arrangement of scene elements are coherent with what is predicted to be desirable by psychophysical models. It has been recognized by researchers that some of the traditional aesthetic domains may be derived from more basic functions of survival and success, such that environmental aesthetics is not a special case of aesthetics but a reflection of its broad and pervasive utility (e.g., Kaplan, 1987).

Identity of Structure-content Properties about Preference and Restoration

A comparison of predictions from all theories revealed shared structure-content properties of greatest relevance to preference and restoration responses (**Table 1**). Each structure-content property was named with an encompassing descriptor for a set of topically related theory predictions. Only shared properties supported by the predictions of at least 3 of the 10 eligible theories were included for further study. Although theories share predictions (i.e., are to some degree co-correlated), it is valuable to consider the context from which the prediction emerges in order to (a) evaluate the relative importance of structure-content properties for preference and restoration, and (b) more ably identify which specific physical attributes are in play.

Naturalness is defined as any type of nature content—the presence of biota, land, water, or sky. Nine of 10 relevant theories predict naturalness as foundational to preference for

TABLE 1 | Identification of shared structure-content properties predicted to be important in preference and restoration responses (across) by key theories from environmental psychology and environmental aesthetics (down).

	Naturalness	Complexity	Structural coherence	structural form	depth cues	Openness	Information gathering support	Access	Safety	Engagement
Biophilia theory (BT)	X	X								
Habitat: prospect-refuge theory (PRT)	X				X	X	X	X	X	
Savanna theory (ST)	X			X	X	X	X	X	X	
Stress recovery theory (SRT)	X	X	X	X	X		X	X	X	X
Environmental information processing theory (EIPT)	X	X	X	X	X			X	X	X
Attention restoration theory (ART)	X								X	X
Environmental aesthetics (EA)	X	X	X	X		X	X		X	X
Environ. aesthetics via urban design (EA/Urban)		X	X	X	X	X	X	X	X	X
Scenic or landscape aesthetics (S/LA)	X	X	X	X	X	X		X	X	X
Design principles (DP)	X	X	X	X	X	X	X	X	X	X
Frequency of concurrence	9	7	6	7	7	6	6	7	9	7

and/or restoration from the landscape. Design principles, rooted in observation and analysis of the natural world, recommend imitation of nature's rules of form and changeability to create a satisfying outcome. By contrast, environmental aesthetics theory via urban design focuses on human built forms in the landscape (EA/Urban: Ewing et al., 2006).

Complexity is defined as information richness of a scene deriving from diversity in its physical structure and physical content. The elements of complexity emerge from variety in line types, forms, textures, or color (DP). Seven theories predict complexity to be related to preference. Biophilia subsumes both structure and content into the term resource variation which refers to the ecological capacity of the environment to provide food, protection, and space for activities important to success (BT: Wilson, 1984). Complexity is predicted as preferred, particularly at moderate levels (SRT: Ulrich, 1983), because it heightens the potential for exploration (EA: Berlyne, 1970; EIPT: Kaplan, 1987). Urban design aesthetics predicts that a walkable city includes the complexity that emerges from variety in building type and spatial grouping, architectural diversity and ornamentation, landscape elements, street furniture, signage, and human activity (EA/Urban: Ewing et al., 2006). At the landscape level, shape complexity and landscape diversity are predicted to be related to preference (S/LA: Schirpke et al., 2013).

Structural Coherence is the degree of unity and visual order often achieved through patterning or linkage of scene components (e.g., a linear succession of tree trunks or canopies. Six theories consider structural coherence of importance to preference or restoration. It is founded on symmetries, repeated elements, homogeneous textures, content or color patterns that bring balance and unity, and the presence of a focal point in a scene (DP; EA: Berlyne, 1971; SRT: Ulrich, 1983; EIPT: Kaplan and Kaplan, 1982). Massing Structural coherence also comes from the balance of repeated elements along an axis (symmetry) and massing of like elements to create a line of visual interest that activates a scene (DP). Structural coherence is also influenced by consistency and complementarity in the scale, character, and arrangement of physical elements like buildings or associated nature elements (EA/Urban: Ewing et al., 2006) and by correspondence between land use and natural conditions of an area (S/LA: Tveit et al., 2006).

Structural Form is present as gestalt, the scene with structural form appears as an organized whole that is more than the sum of its parts (SRT: Ulrich, 1977; EIPT: Kaplan, 1984) This happens with habitat types, like savanna (ST: Orians and Heerwagen, 1992), and biomes, like forest (S/LA: Han, 2007). The gestalt of a city can be defined by its imageability, having a form that is instantly recognizable (EA/Urban: Lynch, 1960). Seven theories predict structural form as important to preference and restoration. It is foundational to the aesthetic response called beauty (EA: Shapshay, 2013). Structural form involves organizing principles like style (e.g., fine textured, highly geometric, DP), emerging from the configuration of lines and planes that can be dominated by curves, straight lines, sharp angles, or some mixture of these.

Depth Cues help us understand the proportional relation and size of objects in a scene. Seven theories predict preference for scenes that support depth perception. A scene with sufficient depth to evaluate the presence of resources and danger is predicted as more preferred (PRT: Appleton, 1975; ST: Orians and Heerwagen, 1992), as are landscapes dominated by the experience of moderate depth (SRT: Ulrich, 1983). A key outcome of successful information gathering is the ability to go deeper into a scene, implying that depth perception is critical to preference development (EIPT: Kaplan et al., 1972). Depth cues reveal proportional relationships between size and distance. Object size can also be inferred by proportional sizing or *human scaling*—using the relative size of known objects or one's own body as the metric for size and distance of what lays beyond (DP). This approach to proportional sizing is enhanced when the arrangement of lines and forms produce a perspective view as happens overtly in the streets of most urban settings (EA-Urban).

At the landscape scale, proportional sizing is based on the relative size of objects in the fore, mid, and background of a scene (S-LA: Schirpke et al., 2013).

Openness is defined as a position along a continuum from physical or visual spaciousness to full enclosure. Six theories predict that degree of openness to be important in preference and restoration responses. Scenes with sufficient openness to evaluate the presence of resources and danger are predicted as preferred (PRT: Appleton, 1975; ST: Orians and Heerwagen, 1992). Openness is a key consideration of designers and urban planners who measure it in terms of volumetric proportion, often using human scale to dimension outdoor spaces that serve well-being (e.g., EA/Urban: Ewing et al., 2006; DP: Alexander et al., 1977). Landscape planners make similar considerations about the form of openness when designing for recreation, habitat restoration, and recovery from disturbance (S/LA: Tveit et al., 2006). Openness has also been defined as nature content arranged with a spatial structure that brings a sense of being surrounded by nature or a sense of nature's boundlessness (EA: Hepburn, 1996). This definition bears directly on the goal of landscape designers charged with creating a sense of the natural world within a dense urban area.

Information Gathering Support includes features of the environment that support the ability to learn more about a setting, often by moving deeper into it. Six theories predict that such support in relevant to preference and restoration responses. Examples include the presence of a physical vantage point to see what is beyond (PRT: Appleton, 1975; ST: Orians and Heerwagen, 1992), a focal point (SRT: Ulrich, 1983), a guiding line to directs visual attention (EA: Berlyne, 1970), plus the degree of visual transparency and the presence of wayfinding tools in the scene (EA/Urban: Ewing et al., 2006). Information gathering is supported by the application of design principles (DP) such the presence of perspective, organizational symmetry of nature–like paired trees along the edge of something, and the configuration of complexity with an organizational spatial hierarchy–like a canopy, understory, and groundcover of vegetation.

Access is about having sufficient and readily understood information that is useful for navigation through an environment. It is a purpose-driven associate of the structure-content property called information gathering support. Seven theories make predictions about features of access that are relevant to preference and restoration responses. Features include having a safe place from which to plan a route (PRT: Appleton, 1975; ST: Orians and Heerwagen, 1992), and having a type of ground surface suitable for navigation (SRT: Ulrich, 1983). Comprehensible movement routes are important in unfamiliar urban areas for wayfinding (EA/Urban: Lynch, 1960) while an obscured view with limited visual access can lead to unpleasant surprises (EIPT: Kaplan and Kaplan, 1989). Path-space relationships and circulation design commonly apply an array of design principles with the goal of maintaining perceptual clarity while providing interest and beauty (DL: authors; Ching, 2007).

Safety is based the presence of environmental form and features that offer protection (or not), especially while gathering information. Nine theories make predictions about features of safety relevant to preference or restoration responses. In terms of environmental structure, safety is typically attributed to places that provide a sense of boundary, access to refuge, or an escape route along with observation point(s) to see what is beyond (PRT: Appleton, 1975; EA-Urban: Chiang et al., 2014; ST: Orians and Heerwagen, 1992). Features of such places include attributes that bring legibility (EIPT: Kaplan, 1987) and the absence of threat (SRT: Ulrich, 1983; Ulrich, ART: Kaplan and Kaplan, 1989). In urban settings, a balance between perceived safety and the degree of naturalness can influence legal regulation (EA: Pearlman, 1988) as well as preference and the capacity for mental restoration (S/LA: Schroeder and Anderson, 1984). The ongoing challenge is to provide safety in balance with positive aesthetic qualities at all landscape scales (e.g., S/LA: Fathi and Masnavi, 2014). Vigilance with safety-aesthetics considerations during design and construction of the built environment, is a hallmark of human settlements (DL: Hill, 1996), for example, the formulas for depth and height of stairs inside or out.

Engagement is based on the presence of something physical that holds the attention. For some this includes the concept of imageability which happens when specific physical elements and their arrangement capture attention, evoke feelings, making landscapes distinguishable, and memorable. (EA/Urban: Ewing et al., 2006; S/LA: Tveit et al., 2006). Seven theories predict preference or restoration from scenes that offer engagement. Engagement can arise in the presence of an attention-getter (SRT: Ulrich, 1983) or from content or structural form that creates mystery or ignites the imagination (EA: Godlovitch, 1994; Brady, 1998). Engagement influences preference especially through ephemera, often the result of weather changes (ART: Kaplan, 1995; S/LA: Tveit et al., 2006). Mystery, the promise of new things to explore if you move further into the landscape, is a consistent predictor of engagement and landscape preference (EIPT and S/LA: Kaplan et al., 1989). Design principles collectively aim for aesthetic engagement, regardless of other goals such as function or safety (DP: authors). Because the engagement attribute is so rich in meaning, we divide it into two categories based on the predictability of physical form that elicits the engagement: (1) engagement from predictable content, includes ever present and fixed objects like a landmark and predictable phenomena such as sunset or fall color, and (2) engagement from unpredictable content, includes ephemera such as rainbows and objects (like foliage) with the capacity for unpredictable movement and interaction with light and water.

Other Considerations. Features of four theories overtly predict the importance of personal meaning to preference and restoration response. This shared property, Highly Meaningful (not shown on **Table 1**), did not move forward to the next phase of work because its measurement is far less relatable to specific physical structure and content features of the environment and is too subjective for direct measurement. Additional information would have to be gathered from subjects for interpretation, such as place-based contributions to preference and restoration (Wilkie and Stavridou, 2013). Theory predictions from the Highly Meaningful category included "being away" and "compatibility" from Attention Restoration theory, "threat" from Environmental Aesthetics theory, and "stewardship", "disturbance", "tidiness", and "historicity" from Scenic or Landscape Aesthetics theory.

Identity of Physical Attributes Associated with Structure-content Properties

The following attribute list articulates concrete predictions about which specific physical structures and content of a landscape are most relevant to preference and restoration. Attribute definition is the final critical step in operationalizing theory predictions.

We identified 62 physical attributes likely to influence preference and restoration. Each of these fulfilled the four requisite criteria: (1) directly manifests a key aspect of at least one theory-derived structure-content property (reported in **Tables 2**–**4**), (2) could be defined with a standard for measurement, (3) had empirical evidence from research or design logic supporting its relevance to preference or restoration, and (4) could be constructed, controlled or conserved during the task of creating preferred and restorative outdoor spaces.

The attributes fell into three design categories—structure attributes that focus on spatial configuration, content attributes that address the identity of non-landscape attributes, and landscape attributes that represent the natural and manmade content of a landscape; they are measured in terms of their coverage area in a scene. For better organization, attributes in each category are subdivided based on dominant commonalities of form or function where this exists. Attribute metrics include the easier-to-measure continuous variables like percent sky and bivariate variables like presence/absence of windows, to categorical variables that were defined to summarize a set of complex considerations.

The narrative that follows includes the definition, a metric, and the rationale for including each attribute. Figures provide a graphical version of definitions for complex spatial attributes. Note that the term Alexander Pattern refers to a pattern number from A Pattern Language (Alexander et al., 1977) that predicts or demonstrates the importance of an attribute to preference or restoration in urban settings.

Structure Attributes (Table 2)

Design logic is the basis of support for each member of this group. Where available, empirical, and design research is mentioned.

The first eight attributes offer metrics for essential aspects of whole scene spatial structure.

Horizon Line Position (1), where earth meets sky (seen or inferred position), is foundational for deciphering one's position and size relative to other objects in view. Horizon line position also contributes to the visual balance in a scene. Measured relative to the base of the frame's vertical axis; 0–100% (**Figure 1A**).

<u>Skyline Position (2)</u>**,** the position of the habitat-sky interface, helps the viewer spatially interpret other structural features. It is the average position of a line of earthbound objects (natural or built) as they meet the sky, measured relative to the base of the frame's vertical axis; 0–100% (**Figure 1B**).

<u>Perspective Type (3)</u> is based on location of a scene's vanishing point(s) and is estimated with visual trajectory lines converging at the vanishing point. The vanishing point(s) is a located in response to the sculptural form of a scene and the information it provides about seeing or moving beyond obstacles. Perspective theory comes from the fact, first articulated in the early Renaissance that apparent size of an object decreases with increasing distance from the eye. Perspective types differ in focal point number and position(s) along the horizon line. In **Figure 1C**, 0, can't tell; 1, No vanishing point (e.g.,–elevation view, close up to a surface); 2, vanishing point in the center of horizon line (central third of frame); 3, vanishing point on right or left side of horizon line (right or left third of frame); 4, vanishing point out of the view frame but can be inferred; 5, Deflected: vanishing point is obscured by other objects so its likely position cannot be inferred (e.g., a trail that disappears around a bend); 6, two vanishing points outside the frame (e.g.,–a building seen on edge or a crossroads); 7, two vanishing points inside the frame but hidden (e.g.,–enclosed space like a courtyard or an outdoor room). Note that a deflected perspective (condition 5) was first shown to be preferred by Kaplan et al. (1972), who interpreted that a deflected was a source of mystery because of its promise for additional information by moving deeper into the scene. Design principles say that a perspective view offers scene information based on location and size of objects relative to one another, and a vanishing point at the horizon gives information about scene depth (Lebreton et al., 2014).

<u>Scenography Type (4)</u> is a gestalt variable that describes the proximity of a viewer to the landscape beyond in terms of its sculptural form and scene depth. Its character states represent a change from more to a less expansive view. This is akin to Alexander Pattern #114 "hierarchy of open space". The key to measuring this variable is to consider the physical experience of scene form rather than its content *per se*. **Figure 1D** illustrates one example—the change in the spatial structure of one's view while approaching a distant woodland and gradually arriving: 0, can't decipher; 1, landscape extends from the viewer to a vista or a bird's eye view of an extended landscape, unbroken by nearby objects; 2, like condition 1 but with very nearby objects; 3, open area in scene's fore to mid-ground with taller objects/vegetation beyond; 4, like condition 3 plus one or a few trees/vertical objects near at hand but separate from the objects/vegetation beyond; 5, open area in the foreground with vegetation/objects that extend continuously into the distance; this type includes most urban street tree scenes; 6, embedded but with a view of what is beyond; 7, embedded with no useful view of what's beyond. Schirpke et al. (2013) found that landscape scenes with foreground elements got higher preference ratings for scenic beauty over those with mid, and far ground elements. Herzog and Bryce (2007) found that preferred focal lengths for prospecting were >100 feet compared to shorter ones less than 20 feet.

<u>Building Distribution (5)</u> signifies the configuration of building or building clusters as they influence a viewer's visual and physical access to what is beyond. In **Figure 1E**, 0, no buildings; 1, all buildings/clusters are distinct with many openings or inferred openings; in urban street perspectives, visual, or physical porosity is evident; 2, building/clusters block the majority of view beyond but are sufficiently open to infer what is beyond; 3, building/clusters completely block the view beyond but a way to move beyond can be inferred; 4,

TABLE 2 | Identity of physical structure attributes that manifest a key aspect of at least one structure-content property.

ID#	Structure attributes	Naturalness	Complexity	Structural coherence	Structural form	Depth cues	Openness	Info gathering support	Access	Safety	Engagement (predictable)	Engagement (unpredictable)	Alexander pattern number[a]
1	Horizon Line position			1		1		1					
2	Skyline position					1							
3	Perspective Type			1	1	1		1	1				
4	Scenography type				1	1	1						114
5	Building distribution				1		1	1	1				53
6	Canyon form				1		1						
7	Water expanse				1	1			1				25
8	Habitat type				1								
9	Trunk position-nearby					1				1			171
10	Framing					1		1			1		134, 239
11	Framing tree count	1		1		1							
12	Viewer in shade				1			1		1			135
13	People proximity					1		1				H	
14	Built surfaces to move			1				1	1				52, 129
15	Visual access to path							1	1				
16	Direct Access to Path			1				1	1				
17	Cover type on circulation			1		1			1				
18	Circulation boundary		1	1				1					
19	Skyline width in frame						1						
20	Skyline geometry		1		1								116
21	Skyline max undulation		1										
22	Skyline vibrancy—proportion	1	1	1								E, F	
23	Skyline vibrancy—length												

[a] *Engagement code and Alexander Pattern number key with* ***Table 3****.*

like condition 3 but with a passage way (able to detect light, vegetation or what is beyond); 5, building/clusters surround the space and views are blocked; 6, like condition 5 but with a passage way (able to detect light, vegetation, or what is beyond). Stamps (2005) reported that the impression of enclosure is related to the percent of a scene covered by surfaces that block vision and movement. Ewing et al. (2006) noted that transparency can be adjusted by the design characteristics of walls, windows, doors, fences, landscaping, and building placement. The access porosity speaks to Alexander Pattern #53 about the importance of gateway experience wherein visual or perceived boundaries are crossed at access points. Interestingly, the passage point itself helps maintain the perceived integrity of the boundary.

Canyon Form (6) is scored when the landform (natural or built) produces the enclosure effect of a canyon; No-Yes. This structural form has been a valuable resource owing to protection from temperature extremes through solar shielding and at nighttime conservation of heat (Levermore and Cheung, 2012).

Water Expanse (7) is based on physical or visual access across a water body; physical access is defined as the ability to cross the water by foot. Its role in well-being is addressed in Alexander Pattern #25 "access to water". In **Figure 1F**, 1, crossable linear waterway (e.g., narrow stream or runnel); 2, water body not crossable and viewer can see its other side; 3, water body not crossable and its entire boundary can be seen; 4, water body not crossable and viewer can't see to its other side. Nature and urban scenes holding water bodies were more preferred and restorative than those without (White et al., 2010).

Habitat Type (8) can be measured in either or both of two ways depending on the image set. Habitat Type 8A is the natural ecological landscape type revealed at least somewhere in the scene. Each type is dominated by characteristic forms that allow identity at a glance: Types are: 0, can't tell; 1, forest; 2, grassland/prairie; 3, forest + grassland/prairie; 4, coastal/edge area of a water body (e.g., lakes, oceans, wide rivers); 5, savanna; 6, desert; 7, tundra; 8, urban/urbanized; 9, agricultural; 10, residential scenes with insufficient information about larger context and close up scenes with human scale structures. Habitat Type in the built environment (8B) emerges from design or management of natural elements. Emulation is founded on the structural form of natural habitat types. It is most often seen in gardens, parks, and greened portions of the built environment Types are: 0, no emulation; 1, forest form; 2, grassland/prairie form; 3, forest + grassland/prairie form (e.g., turf area abutting woodlot); 4, coastal/edge area of a water body (e.g., designed plantings around stormwater pond); 5, savanna-like (e.g., low

TABLE 3 | Identity of physical content attributes that manifest a key aspect of at least one structure-content property.

ID#	Content attributes	Naturalness	Complexity	Structural coherence	Structural form	depth cues	Openness	Info gathering support	Access	Safety	Engagement (predictable)	Engagement (unpredictable)	Alexander pattern number[a]
24	Natural phenomena	1									A-D	E–H	
25	Water form	1	1	1	1		1				D	E–H	64
26	Distinct shadows		1	1		1		1				E	135
27	Focal objects			1				1			1		126
28	Wayfinding objects							1	1				
29	Lighting							1		1		E, F	252
30	Seating							1		1			241
31	Windows		1			1		1		1		G	57, 164
32	Vehicles					1				1		H	52
33	Animal presence	1				1				1	1	H	74
34	People presence					1				1	1	H	100
35	Portrait										1		

Engagement code key: 1-A, diurnal shifts; 1-B, tidal shifts; 1-C, seasonal changes; 1-D, predictable movement; 1-E, wind and light induced change; 1-F, sparkle, visual vibrancy; 1-G, reflections; 1-H, unpredictable movement.

[a]*Alexander Pattern number key: #25, access to water; #51, green streets; #52, network of paths and car; #53, main gateways; #64, pools and streams; #57, children in the city; #74, animals; #100, pedestrian street; #114, hierarchy of open space; #116, cascade of roofs; #126, something roughly in the middle; #129, common areas at the heart; #134, Zen view; #135, tapestry of light and dark; #164, street windows; #171, tree places; #238, filtered light; #239, small panes; #241, seat spots; #252, pools of light (Alexander et al., 1977).*

TABLE 4 | Identity of physical landscape attributes that manifest a key aspect of at least one structure-content property.

ID#	Landscape attributes	Naturalness	Complexity	Structural coherence	Structural form	Depth cues	Openness	Info gathering support	Access	Safety	Engagement (predictable)	Engagement (unpredictable)	Alexander pattern number[a]
60	**NATURE**												
→	Sky veiled (36), Sky open (43), Sky total (49)	1				1	1				A	D–F	
→	Water veiled (37), Water open (44), Water total (50)	1	1	1			1				B	E	
→	Earth veiled (38), Earth open (45), Earth total (51)	1					1		1				
42	Veiling vegetation	1	1	1		1						D	238
52	Non-veiling vegetation												
53	Vegetation total	1	1	1	1	1					C	D, F	
57	Vegetation Canopy												171
58	Vegetation Understory												
59	Vegetation groundcover												51
61	**MANMADE**												
→	Built structures veiled (39), Built structures Open (46), Built structures Total (54)		1		1	1					1		
→	Built ground veiled (40), Built ground Open (47), Built ground total (55)					1	1		1	1			
62	**OTHER**												
→	Other veiled (41), Open other (48), Open total (56)					1							

[a]*Engagement code and Alexander Pattern key with **Table 3.***

grass and spaced out trees, a form found in many urban parks); 6, desert form; 7, tundra form; 8, garden form - stylized (or manmade form - stylized); 9, agricultural form (e.g., urban agriculture plots, raised beds); 10, garden form- not stylized.

The next five attributes address the presence of objects near to the viewer.

Trunk Position of Very Nearby Trees (9) is based on evaluation of trees that are close enough to produce a visceral sense of proximity and are distinctly spatially separated from non-nearby trees. This attribute is addressed in Alexander Pattern #171 which describes how nearby trees produce desired spatial structures that support well-being. Trunk

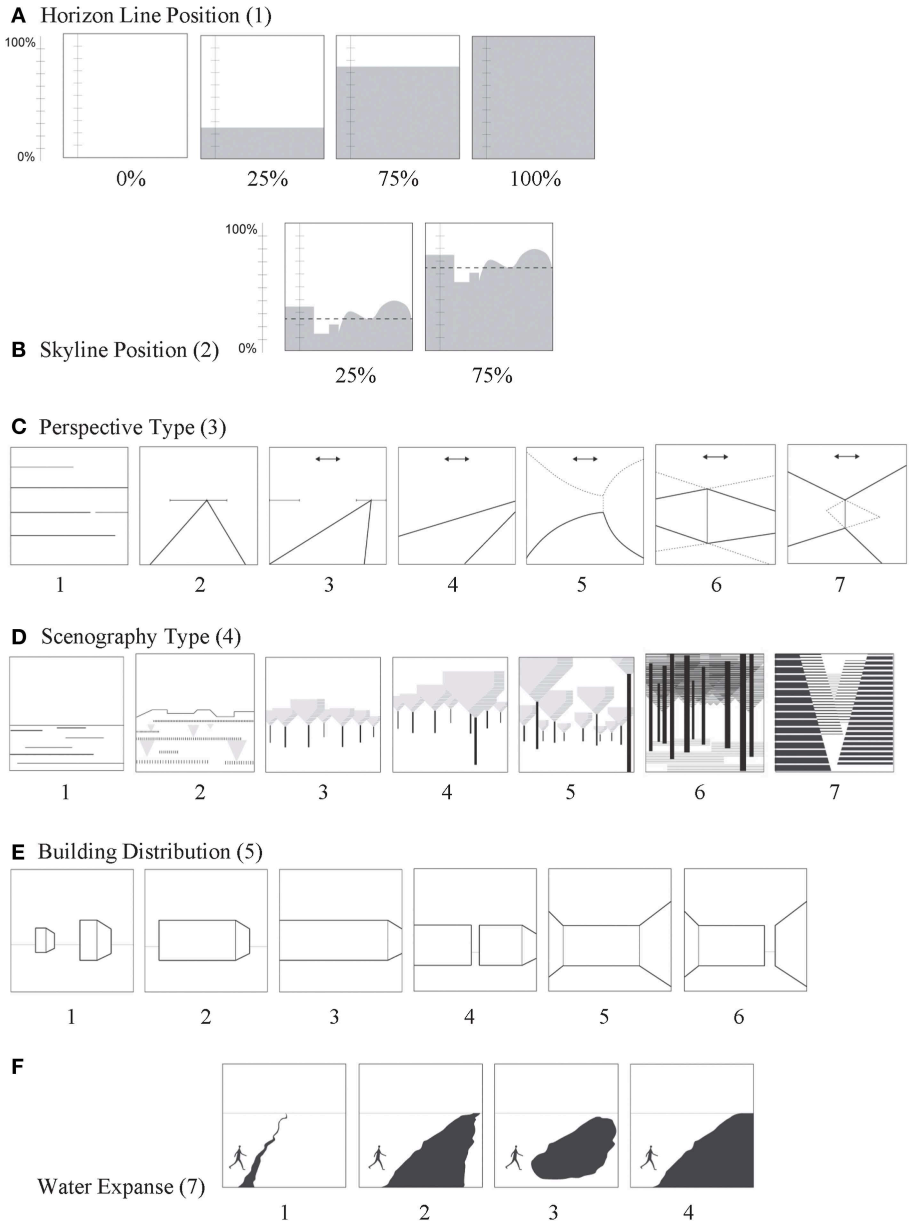

FIGURE 1 | Visualized definitions—character states of attributes with complex spatial definitions, part 1. Attribute ID numbers given in parenthesis. Descriptions of numbered character states for attributes **(A–F)** are given in the section called Structure Attributes.

position is scored relative to trunk intersection (or not) at the top and bottom edges of the scene. In **Figure 2A**, 0, no nearby tree trunks; 1, trunk emerges from bottom frame and ends within frame; 2, trunk emerges from ground plane within scene and continues past top of frame; 3, trunk runs from bottom to top of the scene; 4, 1+2; 5, 1+3; 6, 2+3; 7, 1+2+3. (In cases where Scenography attribute is rated as condition 5, 6, or 7, trunk position of only the nearest tree is scored.)

Framing (10) A framing object is very near to the viewer, it partially obscures what is beyond by having boundaries that extend beyond the image frame. There are 11 framing classes ranging from 1 to 4-sided framing, arranged in all possible edge configurations; 0= no framing. See **Figure 2B**. Because framing acts to engage one's focus to what is beyond, it is routinely used by designers and artists to guide attention. Framing objects support information gathering and offer depth cues by serving as a foreground object for scaling (Schirpke et al., 2013). Ryan et al. (2014) suggest that mystery occurs when a scene's boundaries are partially obscured on one or preferably two edges; this may be particularly so when the framing object is foliage (Gimblett et al., 1985). Alexander Pattern #135 "Zen view" and 239 "small frames"

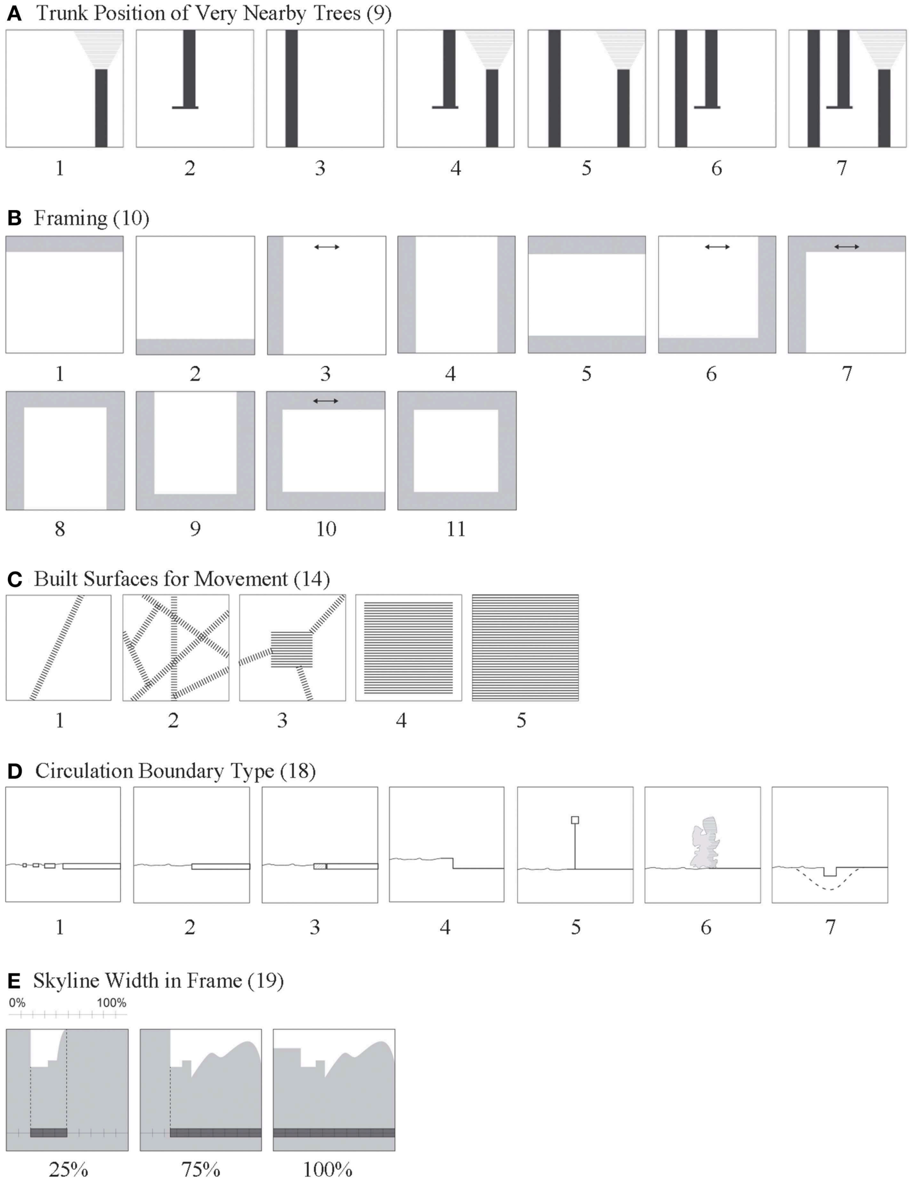

FIGURE 2 | Visualized definitions—character states of attributes with complex spatial definitions, part 2. Attribute ID numbers given in parenthesis. Descriptions of numbered character states for attributes **(A–E)** are given in the section called Structure Attributes.

say that framing objects limit visual access thereby preventing habituation to the view beyond.

Framing Tree Count (11) is the number of sides of a frame with trees as framing objects. Here, 0, 0; 1, 1; 2, 2; 3, 3; 4, 4. As tree count of framing trees goes up, there should be an increased sense of safety and visual linkage which brings a sense of continuity with what is beyond.

Viewer in Shade (12) happens when the vantage point is sheltered in shade which contrasts sharply to a bright scene beyond. The contrast brings greater visual emphasis to what lies beyond; No-Yes. This is akin to the Alexander Pattern #135 "tapestry of light and dark". People Proximity (13) relates the position of people in a scene relative to the viewer's position. The human body functions as a scalar for depth perception (designers call this human scaling). Here, 0, no people, 1, people near, 2, people far, 3, people near and far.

Ability to move through the environment is essential for survival and well-being. The next five attributes concern transit corridors.

Built Surfaces for Movement (14) is defined by the type of the designated circulation system found in the scene, with type based on physical configuration. Alexander Patterns describe benefits of well-designed circulation networks (#52) and nodes (#129). In **Figure 2C**, 0, no circulation system; 1, single path;

2, network of paths; 3, path(s) with node(s), the node being a useful space, not simply an enlarged intersection; 4, free movement over broad space and can see its boundaries (e.g., plaza, patio); 5, free movement over broad space but can't see its boundaries; 6, movement surface is visible but can't read the circulation configuration (no associated graphic in **Figure 2C**). The character states of this variable describe in the ability of lines to direct and orient. Accessibility and provision of a view was also very important to preference in Scandinavian forests (Gundersen and Frivold, 2008). The issue of accessibility can be addressed with this metric by grouping outcomes as yes-no.

Visual Access to Path (15) occurs when the viewer can see a designated path or circulation surface; No-Yes.

Direct Access to Path (16) occurs when the viewer appears to be on a clearly designated path or circulation surface; No-Yes. Sense of depth is heightened when the viewer is on a path that moves into a scene as this provides a perspective view.

Dominant Cover Type on Circulation Surfaces (17) defines the surfacing material on designated circulation surfaces. Types include: 0, no circulation system; 1, sand or compacted soil; 2, mulch; 3, turf grass (mowed); 4, gravel; 5, tiled (tile, paver, flagstone, stone, cobblestone); 6, paved (asphalt/concrete); 7, tiled and paved; 8, wooden. Surface texture and content can influence access, scene unity, complexity, and provide depth cues (e.g., Gibson, 1958; Ulrich, 1977, 1983). Parsons et al. (1995) found that more biodiverse landscapes including those with rough ground cover had lower preference ratings. Such information can be the basis for a design intervention that provides suitable walking surfaces amidst a more ecologically preferable biodiverse ground cover.

Circulation Boundary Type (18) describes the edge condition of (each) identified circulation surface. Character states of this attribute vary by complexity based on the edge condition of the boundary line. In **Figure 2D**, 0, not relevant; 1, fragmented edge; 2, cut edge of manmade material; 3, cut edge includes additional edging of different material; 4, standard street curb; 5, manmade vertical edge (barrier) open or closed; 6, natural vertical edge (e.g., shrubs, boulders), 7, dip, gutter or ditch. Ewing and Handy (2009) found that degree of layering at the edge of streets contributed to the perception of complexity.

Skyline preferences depended on the mix of formal structural characteristics and natural content (Nasar and Terzano, 2010). Several attributes address these considerations.

Skyline Width in Frame (19) measures the distance the skyline extends across the horizontal axis of the frame; 0–100% (**Figure 2E**).

Skyline Geometry (20) is based on the shape of the skyline regardless of content (i.e., built vs. natural objects). In **Figure 3A**, 0, no skyline; 1, sharp corners; 2, curves; 3, straight line; 4, sharp corners + curves; 5, sharp corners + straight lines; 6, curves + straight lines; 7, all shapes. Alexander Pattern #116 "cascade of roofs" is about the visual impact of skyline structure in urban settings.

Skyline Maximum Undulation (21) relates the maximum amount of vertical shift in the skyline. It is measured as the distance between the highest and lowest points of the skyline, and reported as % of the vertical frame height, 0–100% (**Figure 3B**).

Interaction between light and the surface water and/or waxes of foliage produces a sparkle effect or change in vibrancy which can be amplified in response to atmospheric changes, even small fluctuations in wind, thermal, and light conditions.

Skyline Vibrancy, Proportion (22) is the proportion of frame width occupied by the canopy–sky interface, the place where foliage vibrancy is most easily measured (**Figure 3C**).

Skyline Vibrancy, Full Length (23) measures the length of the canopy–sky interface along its path (i.e., includes all vertical shifts). The length is reported as a percent of the frame width and can range from 0% to infinity (**Figure 3D**).

Content Attributes (Table 3)

These attributes are non-landscape objects known to be of relevance to preference or restoration responses.

Natural Phenomena (24) records the presence of engaging aspects of nature including ones that are predictable—like changes associated with the diurnal and seasonal cycles (sunsets and fall color), or unpredictable—like the occurrence of reflective water or ephemeral changes (striking cloud formations). Examples of character states are 1, light beams; 2, rainbows; 3, snowing; 4, fog; 5, visible rain; 6, continue the checklist as needed. Ryan et al. (2014) recommended the use of engaging design elements whose presence or qualities change over time thereby offering a promise of new information to come. Perceptual illusion, where apparent size or proximity of objects alters the viewer's sense of perspective, can result from looking through fog and water (Perea, 2011).

Water Form (25) records the presence of water, its source (installed or natural), its edge form (engineered or natural) and its aesthetic (stylized or natural). Character states include 0, no water; 1, installed water with engineered edges and a stylized aesthetic (e.g., fountain, pool); 2, installed water with engineered edges and a natural aesthetic (e.g., retention pond with naturalized edges); 3, natural water body with (apparently) engineered edges; 4, natural water body with (apparently) natural edges. Engineered edges refers to the use of manmade elements to contain the water. Water in all its forms has been shown as restorative (White et al., 2010). Water body presence always increases openness of a scene. Landscape reflections onto still water bring symmetry and complexity to a scene (Berdan, 2004). Alexander Pattern #64 suggests design approaches that increase water body presence in urban settings based on research about its positive effects.

Distinct Shadows (26) are scored if they bring great visual interest to a scene; No-Yes. Strong patterns appear when trees cast parallel shadows and these can produce affective responses: horizontal lines are associated with tranquility and rest, vertical lines–strength, and ascendancy, oblique or diagonal lines–movement, action and change, and curved lines–quiet, calm and sensual feelings (Berdan, 2004). Shadows also provide depth cues and their direction gives information about time of day and cardinal direction. Painters rely on the same interpretive outcome when adding shadows to convey depth realistically, making 2-D objects appear as 3-D.

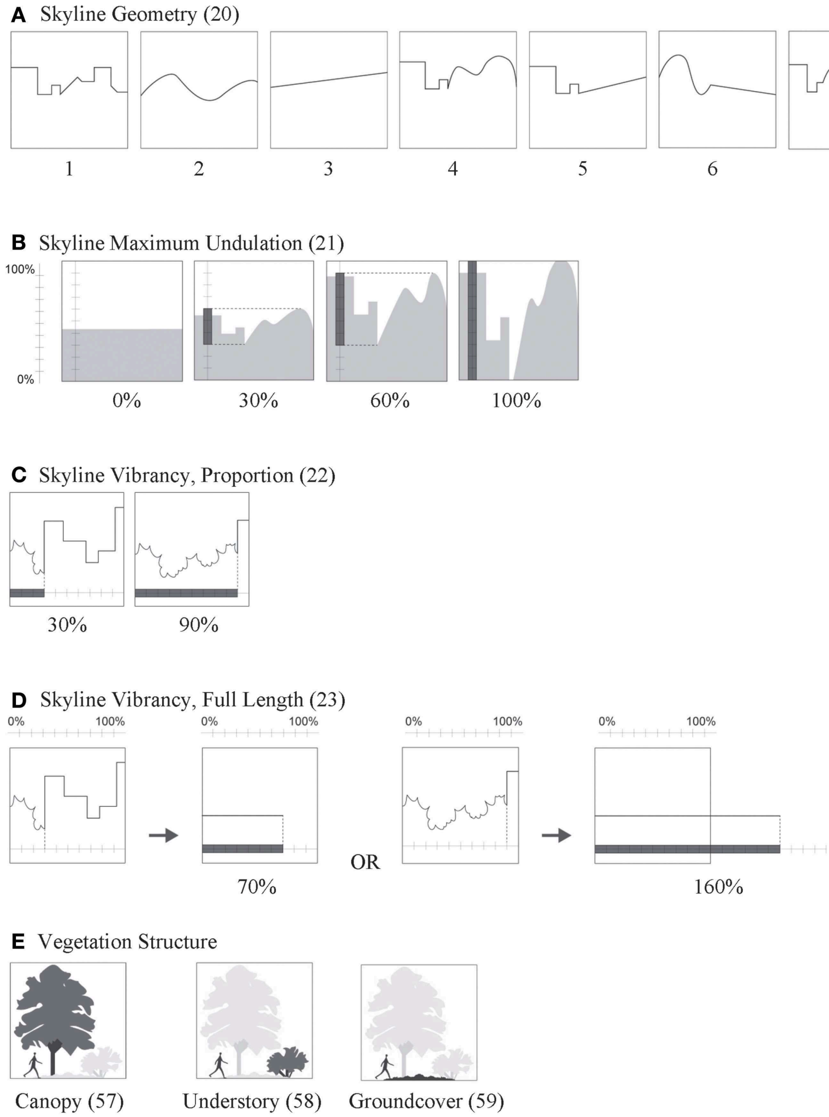

FIGURE 3 | Visualized definitions—character states of attributes with complex spatial definitions, part 3. Attribute ID numbers given in parenthesis. Descriptions of numbered character states for attributes **(A–D)** are given in the section called Structure Attributes; for attribute **(E)** see section called Landscape Attributes.

Focal Objects (27) engage the viewer and guide the visual investigation of what is around. They can be an object or element that is unusual to scene content. Focal objects provide a strong sense of organization, bringing coherence to the scene. Presence is scored (No-Yes) and object type is identified. Examples include public art, a fountain or a prominent garbage bin in a pastoral scene. Alexander Pattern #126 discusses design foundations of focal objects in pleasing urban settings.

Wayfinding Objects (28) are scored when signage, public landmarks or other wayfinding objects are present; No-Yes. Information that supports wayfinding is critical to psychological well-being (Lynch, 1960).

Lighting (29) is scored when a manmade light source of any type is present; No-Yes. Street lights are the most typical. Lighting offers safety (Stamps, 2005), enhances the usefulness of wayfinding cues (Lynch, 1960), and, in the presence of foliage, can heighten engagement in ways akin to sun-foliage interactions which produce shadow casting and vibrancy effects. Alexander Pattern #252 describes the role of light in creating functional social spaces.

Seating (30) is the presence of an object designed for, or obviously used for sitting; No-Yes. Seating serves as a place to pause and collect information. If well placed, it offers safety by acting as a refuge. Abdulkarim and Nasar (2014) found that the presence of seating in an urban is associated with a restorative effect. Alexander Pattern #241 discusses why seat location/orientation is far more important than its style.

Windows (31) are visible to the viewer; No-Yes. Alexander Patterns #57 and #164 explain the positive impact of street windows on safety and neighborhood life. Windows also bring complexity and unpredictable engagement to a scene with their reflections (Berdan, 2004). Size and proportion of windows help establish the scale of a building (Ching, 2007).

Vehicles (32) include any type of motorized vehicles visible to the viewer; No-Yes. Vehicles are relevant to safety (harboring friend or foe, see Alexander Pattern #52), are engaging because movement pattern is unpredictable, and when parked along a street, act as a barrier to moving traffic (Clifton et al., 2008).

The Presence of Animals (33) and People (34) is related to safety (friend or foe), engagement, and depth cues come from proportional scaling using body size to infer distance. Animal presence also indicates naturalness. Alexander Pattern #74 argues that animal presence influences well-being on par with plants. People presence can serve as well-being indicator of a functional public social fabric. (Alexander Pattern #100). Both attributes are scored: 0, none; 1, 1; 2, 2 to 5; and 3, >5. The range and split points suited the data set used for testing. See Discussion Identifying Additional Attributes and Expanding Metrics on making place-based adjustments to metrics of these attributes.

Portrait (35) happens when a single subject dominates the scene. Common portrait subjects are 1, flower or small plant; 2, person or people; 3, animal(s); 4, other (and identify what it is); 0, not a portrait. Since, portrait subjects are often a source of fascination to the photographer (Berdan, 2004), this attribute is predicted to be informative in research where images are taken by the subjects.

Landscape Attributes (Table 4)

A hierarchy of attribute measurements starts with nature, manmade, and "other" landscape categories, the latter including humans, animals and undecipherable content (**Figure 4**). All landscape attributes are measured as percent of the total viewing frame area; each has a value from 0 to 100%. Nature and manmade elements are divided into subgroups, most with a demonstrated impact on preference and restoration. For nature these include Sky (Hepburn, 2010), Water (Völker and Kistemann, 2011), Vegetation (e.g., Berman et al., 2008), and Earth, the latter defined as any ground which is neither vegetated nor manmade (e.g., dirt, sand, rocks). Manmade groups are Built Structures, which include buildings and any manmade objects like sculptures or signage, and Built Ground which includes any ground surface whose materiality has been adjusted by construction such as paved roads or wooden boardwalks. Empirical work and the experience of designers supports a role for manmade structures in well-being outcomes (Alexander et al., 1977). This underlines the need to move away from dichotomizing nature and built up urban areas as the point of comparison.

An interesting discovery happened early our process when trying to quantify the proportion of a scene holding vegetation, a seemingly easy task. While examining images, there were many instances where open matrix vegetation (e.g., an open web of leaves surrounding an extended tree branch) partially masked what was beyond. What was beyond was generally understood, but sometimes with less certainty. We call this a *veiling effect* (e.g., **Figure 5**). Further investigation of images and extended field observation by the lab team made it clear that veiling is a common occurrence and often (a) heightens engagement by presentation of mystery (what lies beyond this thin veil?), (b) brings fascination via the amplified sparkle/shimmer due to the interplay foliage with light and breeze, and (c) increases depth perception because its layering effect and its production of shadows support the use of proportional scaling. Akin to a veiling effect, Kaplan et al. (1972) reported that a most preferred scene type had a well-lit clearing that was partly obscured from view by intervening foliage. The veiling effect is also akin to Alexander's pattern #238 on the value of filtered light. Recognition of the veiling effect required that landscape attributes be quantified in two ways—recognizing or ignoring veiling.

When veiling is considered, landscape elements are measured separately as veiled or open (unveiled). Veiled attributes are: Sky Veiled (36), Water Veiled (37), Earth Veiled (38), Built Structures Veiled (39), Built Ground Veiled (40), and Other Veiled (41). Veiling Vegetation (42), is the sum of all attributes and can be used to test hypotheses about the total veiling effect.

Unveiled attributes, are not covered by any intervening foliage, include: Sky Open (43), Water Open (44), Earth Open (45) (**Figure 6**), Built Structures Open (46), Built Ground Open (47) (**Figure 7**), and Other Open (48). To account for 100% of image content, the variables above are added to Non-veiling Vegetation (52), vegetation not participating in veiling.

When veiling is ignored, each landscape group is represented as the addition of its Open and Veiled components: Sky Total (49), e.g., Sky Open + Sky Veiled; Water Total (50), Earth Total (51), Built Structures Total (54), Built Ground Total (55), Other Total (56). To account for 100% of image content, the variables above are added to Vegetation Total (53) shown in **Figure 6**, which is the sum of Non-veiling Vegetation (52) and all Veiling Vegetation (42).

Vegetation is also evaluated in terms of vertical structure (**Figure 8**) by subdividing Vegetation Total (53) into Vegetation Canopy (57)–vegetation 8 feet or greater, Vegetation Understory (58)–plants ranging from 3 to 8 feet tall, and Vegetation Groundcover (59)–herbaceous plants or low shrubs up to 3 feet tall. Plant heights were estimated by proportional scaling, comparing the size of plants to known objects in the scene or knowledge of their size relative to human scale (**Figure 3E**).

The overall balance of nature and manmade elements in a scene can be assessed Nature (60), Vegetation Total + Sky Open + Water Open + Earth Open; Manmade (61), Built Structures Open + Built Ground Open; and Other (62), Other Open. Note that all veiled areas are included in Vegetation Total.

Discussion

This research produced a systematic approach to meet the challenge of identifying which specific physical attributes of an

FIGURE 4 | Comparison of coverage by Nature (60), Manmade (61), and Other (62) elements for three scenes. Attribute ID number given in parenthesis.

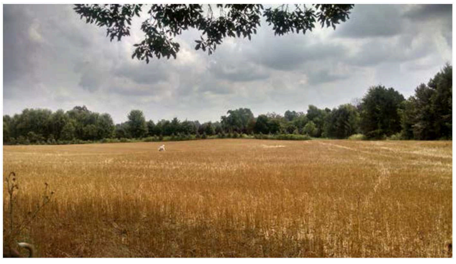

FIGURE 5 | Veiling: the superimposition of open matrix foliage on any non-plant surface. Along the top of the viewing frame, sky is veiled.

environmental setting are most likely to influence preference and restoration responses. Physical attribute identification was the result of a triangulation process invoking environmental psychology and aesthetics theories, principles of design founded in mathematics and aesthetics, and empirical outcomes and design practices regarding the role of specific physical attributes in preference or restoration responses. The first product was identification of 10 structure-content properties predicted by theory to contribute to preference and restoration (**Table 1**). The second product was identification of 62 measurable physical attributes, each of which attended to one or more of the 10 theory-based properties and was linked empirically to preference or restoration (**Tables 2–4**).

The attributes can be used in preference-restoration research during pre-study image selection or post-study interpretation of results to enable a more specific type of scene interpretation than presently exists. Consider depth cues, one of the 10 properties of a preferred or restorative scene (**Table 1**). In 1950, Gibson demonstrated that depth perception is based on perceived relationships between objects and their proportional size relative to a background surface, with ground surface being the most important (Gibson, 1950). Although this has been confirmed many times since (e.g., Bian et al., 2005), depth is a variable rarely found in empirical studies of preference/restoration, most likely because it is tough to measure in 2D images [e.g., protocols in Lebreton et al. (2014) for images and Schirpke et al. (2013), for landscape metrics using GIS modeling].

However, we have identified many readily measured physical attributes that provide depth cues (**Tables 2–4**) with our approach. The depth cue array includes 9 structural attributes–position of the horizon line (1) and skyline (2), type of perspective (3) and scenography (4), degree of water expanse (7), position of

FIGURE 6 | Visual comparison of natural landscape components found in three scenes. Nature is defined by the attributes (ID#): Sky Open (43), Water Open (44), Earth Open (45), and Vegetation Total (53) which includes all areas covered by veiling vegetation.

nearby tree trunks (9), position of objects that frame a scene (10), proximity of people–for human scaling (13), and the dominant groundcover type on circulation surfaces (17). Five content attributes are the presence of distinct shadows (26), seating (30), windows (31), vehicles (32), and people (34), all of which serve as proportional scales for sizing in support of distance estimation. Landscape attributes include the total area of veiling vegetation (42) or any of its subsets (32–41). This group of attributes can be used in any combination to test hypotheses about the physical nature of depth cues that contribute to preference and restoration. The same can be said for attributes associated with the other nine structure-content properties that emerged from theory evaluation. Such research outcomes are exactly what is required for evidence-based design.

Our protocols for attribute identification ignore the debate about relative contributions of cognitive, affective, and other aspects of human response to nature such as cultural tradition and the nature of transcendence. We think these very issues, can be better investigated with a well-founded and common set of physical attributes for testing.

Hypothesis Testing

The physical attributes listed on **Tables 2–4** articulate a starting point for deciphering which scene stimuli dominate or

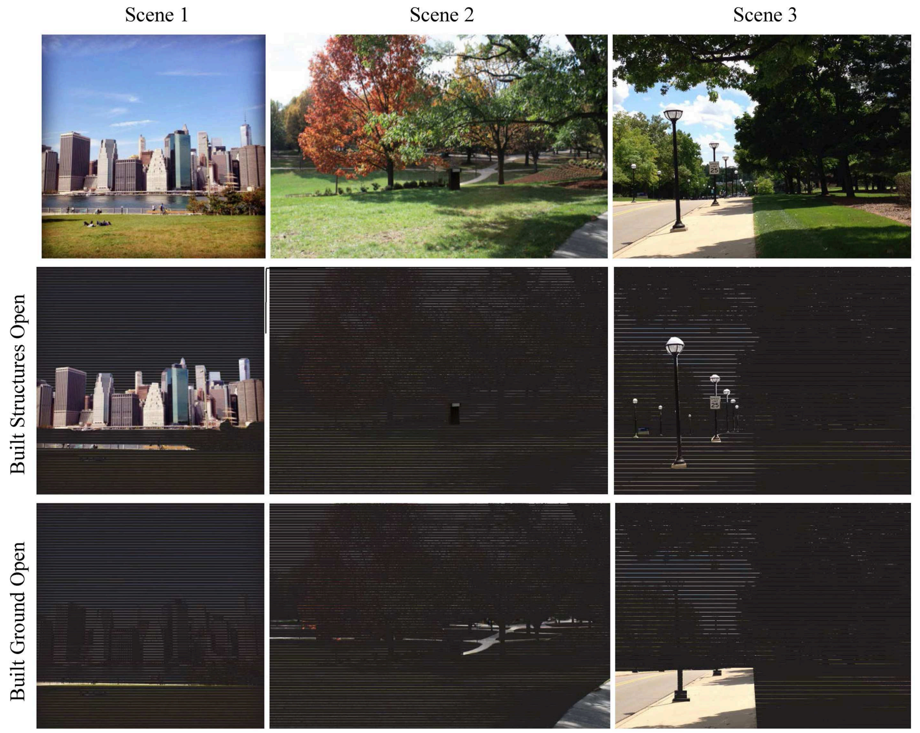

FIGURE 7 | Visual comparison of manmade landscape components found in three scenes. Manmade is defined by attributes (ID#): Built Structures Open (46) and Built Ground Open (47).

collaborate in preference and restoration responses. It was our intent to provide a manageable approach for testing hypotheses about which physical attributes of a scene are likely to intensify, neutralize, or reduce the impact on preference or restoration over a range of outdoor settings. With a diverse selection of attributes, it is possible to determine if they act singly or in concert—and if so, in what combinations. For example, data can be analyzed to determine (a) if and how cohorts of attributes contribute to preference and restoration, (b) whether there are critical points along the continuum from highly natural to highly urban where different physical attribute cohorts are most functional in generating preference and restoration, (c) the importance of the sky as a nature element in highly built areas, and (d) whether the amount of veiling in scene is related to preference and fascination.

Attributes can serve as independent variables or clusters to evaluate the physical premises of preference and restoration outcomes using standard statistical methods such as cluster and factor analyses, multiple, and logistic regression. Where data analysis identifies specific attribute clusters that bring preference and restoration, we will be closer to understanding how to design for a gestalt reaction that brings positive outcomes.

How the results in **Tables 2–4** are used will depend on the question asked by the investigator. Consider the attribute Horizon Line Position (#1, **Table 2**). One researcher might choose to measure the contribution of horizon line position to preference or restoration responses while another might investigate which or how the 3 theory-based-properties of horizon line position are involved in preference and restoration (e.g., a viewer's sense of structural coherence in a scene, the provision of depth cues, and support for information gathering). And yet another researcher might read **Tables 2–4** vertically to identify which attributes are related to a property (e.g., depth cues), then test to discover which ones make the strongest contribution to preference and restoration, and whether the result is maintained across landscape types, cultural context, age class, and so on.

Identifying Additional Attributes and Expanding Metrics

The attribute list and its associated metrics were designed for universal application, useful for any landscape type. However, this list is not meant to be exhaustive. Place-based differences, the goal of an investigation, the evolution of theory, and the availability of new technologies will require the development of new attributes and metrics. Our research offers a protocol for identifying appropriate and measurable attributes and adding new metrics to existing ones.

While our sight was set on developing the most robust definitions, there is likely some bias because most of the images used during metrics building came from natural or moderate density urban settings in the relatively flat Midwestern U.S. Consideration of very different geographic settings, habitat types or land use could precipitate identification of more attributes

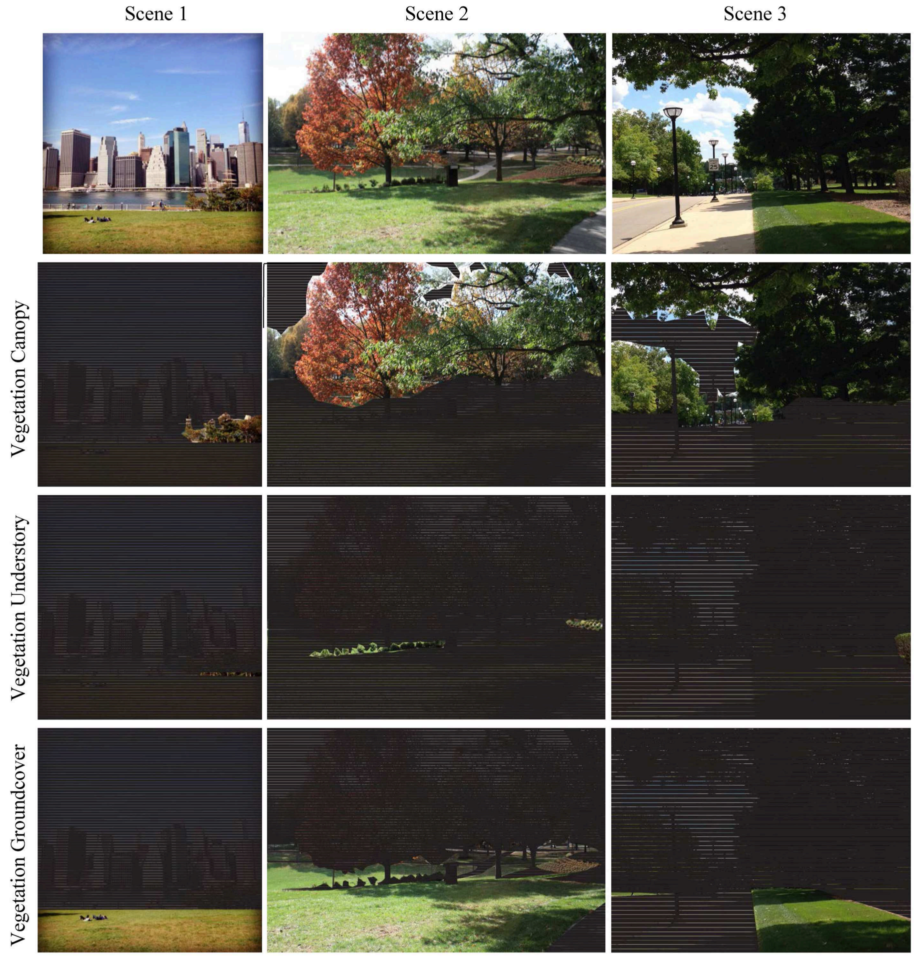

FIGURE 8 | Analysis of vegetation attributes (ID#) in terms of vertical structure for three scenes in terms of Vegetation Canopy (57), Understory (58), and Groundcover (59).

owing to a greater range of structure and content than we dealt with. Karmanov and Hamel (2008) point out the paucity of research on restorative features of urbanized areas beyond those supplied by green spaces and water. New attributes for highly urbanized environments could be identified and defined with the method presented here.

Evaluation of places with different landscape structure might require new metrics for an existing attribute. For example, in a desert setting where trees do not exist, Trunk Position of Very Nearby Trees (9) could be customized by specifying tall, sturdy cacti for trees (e.g., *Yucca brevifolia*, Joshua Tree). If instant cover (safety, **Table 2**), is under study, this choice would be appropriate. However, if the cactus is covered with thorns (e.g., *Carnegiea gigantea*, Saguaro Cactus), interpretation of the response might be different. Both types of cacti would be good tree substitutes if the nearby "tree" is serving as a proportional scale (depth cue, **Table 2**). The point is that customization should recognize theory predictions that underlie an attribute. When adding or reinterpreting a character state it is important to go back to the theory basis of the attribute's selection (shown in **Tables 2–4**) when designing an experiment or interpreting its results.

Some attribute metrics scored as No-Yes (26–32) can be expanded to answer different questions. It would be valuable for a designer to know, for example, if the contribution of window presence (31) to preference or restoration depends on the number of windows or the percent of a viewing frame occupied by windows. Expanded metrics for window presence would be more sensitive to differences in the impact of windows in different settings such as city center, suburban residential, urban parkland, and wildlands. Such information would fortify the evidence-base for well-being designers who can use the information to choose vantage points or create screens to keep the amount of visible window within an optimal range.

Other place-based adjustments to attributes include those scored by frequency class. Adjustment of range and split points should attend to the range of response found in a data set or the need for greater specificity owing to the hypothesis being tested. Only 2 of the 62 attributes presented here are eligible for this type of adjustment—Animal Presence (33) and People Presence (34).

The range and split points for both are: 0, none; 1, 1; 2, 2 to 5; 3, >5 because a focus on low counts had the greatest discriminatory power with the data set used. However, data sets with scenes from city centers or recreational areas might benefit from a larger range with more split points. Simple counting is one such adjustment.

The insights from design theory and practice were indispensable as we identified attribute candidates and developed metrics. They also suggest which adjustments to the building blocks of environmental structure (like horizon line position or sky: manmade proportions in a scene) are likely to impact the viewer's sense of spatial structure. Consequently, we strongly recommend that research teams include both scientist and designer for work on attribute development, translational application, and evaluation of evidence-based designs that use such research outcomes.

The Challenge of Defining Less Measurable Attributes

Some design principles involved with naturalness are less tractable because analysis methods are time consuming or require expertise or available computer algorithms. Evaluation of structural proportion and fractal geometries are in this group. Color, a popular focus of human-nature interaction studies, is complex to evaluate, even when the focus is on vegetation (which is often not green; what is green anyway?). In fact, the color of nature is highly variable. Computer algorithms for measuring color are excellent, their limitation coming only from the color trueness of the image under evaluation (Nishiyama et al., 2011). The field of visual aesthetics has made significant headway in its methodology for evaluating human preference in terms of color and spatial structure (Palmer et al., 2013), as well as complexity, symmetry, line orientation, spatial proportion, compositional balance, and the role of meaningful objects in biasing compositional sense. For example, Berman et al. (2014) found that degree of perceived naturalness was highly correlated with low level visual features defined by average color saturation and hue diversity, as well as the density of contrast changes and straight lines.

Why Measuring Attributes Improves Image Selection and Interpretation

Most importantly, the approach we present supports image selection along a more finely grained continuum from natural to manmade, the range of environments encountered in everyday life. This is of particular value for tests about the role of personal experience or cultural norms in response to nature, where the standard dichotomous choice (natural vs. urban) is not sufficient. We suspect that a more finely-grained natural-urban scale is needed to locate optimal restoration points for an upstate New York suburban community compared to the one living in Manhattan.

The choice of images for testing will also improve by using multiple criteria to identify incorrect assumptions (e.g., when tree presence does not have a positive effect) and to detect potentially confounding effects (e.g., why preference or restoration response to water is highly variable). Practically speaking, attribute scoring of an image offers a guided examination that uncovers often unrecognized cues involving depth perception, human scaling, unnoticed content, etc.

Using Research on Physical Attributes to Provide an Evidence-base for Design

Landscape architects, architects, and planners shape and form the spaces that humans use, giving them great restorative agency in the world. For the best outcome, well-being designers require information about which physical attributes of nature—spatial structure and content, are most likely to support health, especially in urban settings. Research outcomes about the contribution of physical attributes to preference and restoration (some already known) can be used to guide design professionals aiming to join aesthetics, ecological, and psychological principles for the production of restorative urban spaces. Here, are a few examples of how evidence-base design could translate research outcomes. (1) Research outcome: the presence of framing foliage triples preference/restoration ratings of the urban scene holding <20% total vegetation; design solution: in densely built areas, locate trees/ plants with appropriate architecture so that favored stopping places include nearby foliage in their viewshed. (2) Research outcome: as the length of skyline vibrancy increases so does preference/restoration; design solution: maximize the opportunity for distant views with skylines dominated by tree canopies (a view which is borrowed and free) and minimize views of manmade skylines by masking or redirecting attention from them. (3) Research outcome: preference/restoration drops by half when horizon line position is not discernable from a seating area in a public park; design solution: provide other kinds of location cues, adjust the view so the horizon line is visible, or if possible, relocate the benches for a view including horizon line.

The development of a better evidence base for well-being designers will provide a realistic premise for urban greening that extends far beyond the broad generalizations currently available–like provide 10–20% natural areas and be sure that water in some form is encountered within a 1 mile radius of any residence. As urban density increases worldwide, so does the domination by built objects and the loss of ecosystem services including psychological ones (Irvine et al., 2010). There is the need to learn more specifically about the type of nature that best supports well-being (Bratman et al., 2012; Shanahan et al., 2015). In addressing this question, our research is offers a route to find these answers. The knowledge can be applied at all scales from bench placement and streetscape design, to large-scale city park design and selection of path systems in wild places.

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The ideological divide and climate change opinion: "top-down" and "bottom-up" approaches

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The United States wields disproportionate global influence in terms of carbon dioxide emissions and international climate policy. This makes it an especially important context in which to examine the interplay among social, psychological, and political factors in shaping attitudes and behaviors related to climate change. In this article, we review the emerging literature addressing the liberal-conservative divide in the U.S. with respect to thought, communication, and action concerning climate change. Because of its theoretical and practical significance, we focus on the motivational basis for skepticism and inaction on the part of some, including "top-down" institutional forces, such as corporate strategy, and "bottom-up" psychological factors, such as ego, group, and system justification. Although more research is needed to elucidate fully the social, cognitive, and motivational bases of environmental attitudes and behavior, a great deal has been learned in just a few years by focusing on specific ideological factors in addition to general psychological principles.

Keywords: U.S. political psychology, ideology, climate change, system justification, liberal-conservative divide

INTRODUCTION

The scientific community exhibits widespread agreement about anthropogenic climate change and the need to reduce greenhouse gas emissions (Anderegg et al., 2010). For a number of reasons, including the intergenerational nature of climate change policy, whereby sacrifices made today will not yield dividends for decades to come (Schelling, 1995; Bazerman, 2006; Jacquet et al., 2013), greenhouse gas reductions will not be accomplished easily. Despite the fact that obstacles are universal, there is considerable variation in the degree to which individual and corporate actors (including nation-states) have sought to mitigate fossil fuel use—a fact that should, and does, interest social scientists.

Due to its disproportionate global influence in terms of carbon dioxide emissions (second only to China) as well as its role in affecting international climate policy, the U.S. stands out as an especially important context in which to examine social, psychological, and political dynamics. In 2009, a task force of the American Psychological Association (APA) identified numerous reasons for the public's lack of urgency on the issue, including old habits, feelings of personal insignificance, uncertainty about the severity of climate changes, mistrust of information, the belief that the costs of climate change will occur later in the future than scientists expect, and high rates of denial and skepticism (Swim et al., 2010). Indeed, skepticism about climate change is higher in the U.S. than in other countries (Anderegg et al., 2010; Poortinga et al., 2011; Engels et al., 2013)—and this fact itself requires deeper explanation. It seems especially pertinent that denial and skepticism are not uniformly distributed across the political landscape; conservatives express greater skepticism about climate change and more opposition to climate-related policies than liberals (e.g., Weber and Stern, 2011; Liu et al., 2014).

In the APA report, Swim et al. (2010) cited just two studies addressing the ideological divide over climate change policy (Dunlap and McCright, 2008; Hardisty et al., 2010). Since that time, a literature has emerged to analyze liberal-conservative differences in climate-related attitudes and behaviors, including studies that have highlighted motivational factors that help to explain the ideological divide and its implications for political action (or inaction) when it comes to climate change. Jost et al. (2009) proposed that ideological outcomes are typically the joint product of "top-down" elite-driven forms of communication (i.e., the discursive superstructure) and "bottom-up" psychological factors that make citizens more or less receptive to those forms of communication (i.e., the motivational substructure). In an effort to integrate "top-down" and "bottom-up" approaches, we review recent research on the U.S. ideological divide that is focused specifically on climate change (rather than environmental concerns more broadly, but see, e.g., Dunlap et al., 2001; Xiao and McCright, 2007; Feygina et al., 2010; Liu et al., 2014).

THE IDEOLOGICAL DIVIDE: PUBLIC OPINION DATA

Since the 1980s, U.S. political leaders have been resistant—symbolically and operationally—to domestic action and international cooperation on climate change (Jamieson, 2014). Polarization among the American public has been on the rise since the 1990s (Guber, 2013). In a 2010 Gallup survey of 1,014 adults in the U.S., 74% of liberals agreed that "effects of global warming are already occurring," whereas only 30% of conservatives concurred (Jones, 2010). Public opinion surveys of

1,024 Americans in 2012 revealed that 42% contend that climate change claims are "generally exaggerated" and that political conservatives are more skeptical of climate change than liberals (Saad, 2012). Even among Republicans, there appears to be an ideological split: a survey of 1,504 Americans in October 2013 found that 61% of non-Tea Party Republicans believe that there is solid evidence of global warming, as compared to only 25% of Tea Party Republicans (Pew Research Center, 2013).

While some surveys suggest broad support for certain climate change-related policies (e.g., tax breaks for renewable energies; Krosnick and MacInnis, 2013), other studies reveal pervasive ideological cleavages. In a survey of 209 Pittsburgh residents concerning fossil fuel consumption, Republicans were 4.5 times and Independents were 4.2 times more likely than Democrats to reject regulations proposed to limit SUVs and trucks (Attari et al., 2009). Gromet et al. (2013) surveyed 657 U.S. residents and found that people who identified themselves as politically conservative were less supportive of investment in energy-efficient technology than those who were more liberal. Based on a survey of 375 residents from Michigan, Bidwell (2013) concluded that opposition to commercial wind farms was "fueled by conservatism."

Natural field experiments also highlight the extent of ideological division. Providing households—which account for approximately 38% of U.S. total emissions (Dietz et al., 2009)—weekly or monthly feedback about their home energy use (compared to that of their neighbors) can lower overall energy consumption (Schultz et al., 2007). Costa and Kahn (2013) analyzed data from 81,722 homes (48,058 of which were in a control group) over the course of nearly 3 years and connected homeowners with voter registration records (i.e., party affiliation). Compared to Democrats, Republicans were more likely to opt out of the energy program, less likely to indicate that they liked the home energy reports and found them useful, and were less likely to reduce their energy consumption during the course of the intervention.

"TOP-DOWN" FACTORS: INSTITUTIONAL EFFECTS ON COMMUNICATION AND DISCOURSE

Evidence suggests that there are clear "top-down" institutional forces at work when it comes to skepticism about climate change and political acquiescence, and that these forces exacerbate the ideological divide (see **Figure 1**). Sociologists Dunlap and McCright (2011) link the rise of climate change denial to corporate and right-wing strategists, such as Richard Mellon Scaife and the Koch brothers (who have given at least $48 million—half of that since 2005—to groups that actively deny global warming). Scholars and investigative journalists have become increasingly concerned about the historical role of corporations and politicians in deceiving the public about the risks of a wide range of behaviors associated with tobacco use, pollution, and climate change (e.g., Michaels, 2008; Oreskes and Conway, 2010).

Evidence from cross-national studies confirms that information communicated in the U.S. is distinct from what is communicated in the rest of the world. Bailey et al. (2014) compared climate change coverage in 2001 and 2007 in U.S. (*New York Times* and *Wall Street Journal*) and Spanish newspapers (*El Mundo* and *El Pais*) and found that U.S. newspapers used twice as much "hedging" language—words that suggest uncertainty (e.g., "inaccurate" or "speculative"). An analysis of 2,064 print media articles spanning six countries (Brazil, China, France, India, U.K., and the U.S.) from November 2009 to February 2010 revealed that the U.S. had the highest proportion of articles—one-third—expressing skeptical positions about climate change (Painter and Ashe, 2012).

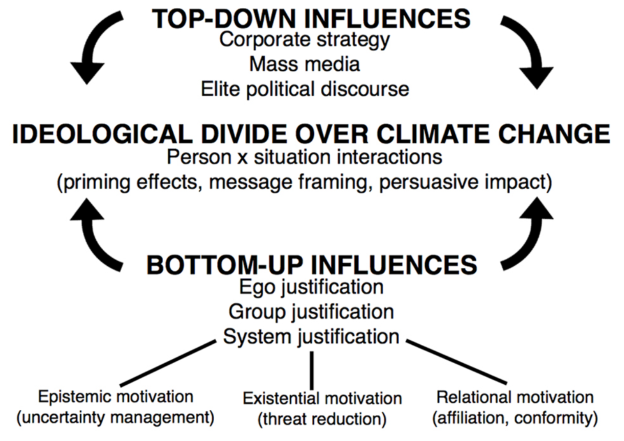

FIGURE 1 | Contributions of top-down and bottom-up influences to the ideological divide over climate change.

Within the U.S., print media between 1998 and 2002 expressed more uncertainty about climate change than scientists registered (Boykoff and Boykoff, 2004). Content analysis of media in subsequent years has underscored high variability among news outlets. Studies comparing cable news television channels (i.e., Fox News, CNN, and MSNBC) demonstrated that Fox News has emphasized scientific uncertainty more than other networks and has focused more on stories that question the existence of human-caused climate change (Feldman et al., 2012). Elsasser and Dunlap (2013) analyzed 203 opinion editorials written by 80 U.S. conservative columnists published between 2007 and 2010 and found that all of them expressed doubts about climate change and/or climate science. Hmielowski et al. (2014) performed longitudinal research, surveying 2,497 U.S. residents in the fall of 2008 and 1,036 in a follow-up survey in the spring of 2011. The researchers discovered that the more individuals reported using conservative media, the less certain they were that climate change was real. Moreover, conservative media use was negatively associated with trust in science over time, suggesting one powerful way in which mass media influences beliefs.

IDEOLOGICAL DIFFERENCES IN PROCESSING "TOP-DOWN" INFORMATION

Several studies have investigated the ways in which "top-down" forms of elite communication (and framing) interact with "bottom-up" factors such as the ideological inclinations of the audience. This work suggests that exposure to the same information can produce divergent effects—as a function of the message recipient's political orientation—when it comes to attitudes about climate change. For example, an ideological divide was readily apparent in response to the 2007 report of the Intergovernmental

Panel on Climate Change (IPCC). Budescu et al. (2012) asked 556 Americans to interpret the report's use of words (rather than numerical percentages) to describe risk probabilities. Overall, respondents underestimated the problem of climate change as characterized in the report. For instance, the phrase "very likely," which was intended to convey a probability of greater than 90% in statements such as "it is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent," was interpreted, on average, as suggesting a 62% likelihood. The underestimation effect was especially dramatic among political conservatives, who interpreted "very likely" as reflecting a probability of approximately 50%. A web experiment involving 400 Americans revealed that for conservatives the phrase "global warming" was associated with certain outcomes (such as rising temperatures and melting ice), whereas the phrase "climate change" was not; for liberals, there were no such differences in association (Schuldt and Roh, 2014).

Hardisty et al. (2010) studied 337 Americans to determine the effects of framing an environmental cost as a "tax" or an "offset" when it came to the (hypothetical) purchase of an airline ticket that included a surcharge for carbon dioxide emissions. Participants evaluated a regular ticket and a more expensive ticket similarly when the costlier ticket was framed as including an "offset," but Republicans and Independents were significantly less approving of the costlier ticket when it included a "tax." Only 23% of Republicans selected the more expensive option with the environmental "tax," as compared to 56% of Republicans who selected the same ticket when it contained an "offset." (Most Democrats were supportive of the surcharge regardless of whether it was described as an "offset" or "tax").

Gromet et al. (2013) provided participants with $2 and asked them to purchase (and take home) one of two light bulbs—either an incandescent bulb or a compact fluorescent light (CFL) bulb, which is considered a more environmentally friendly choice. All participants were given information about the advantages of purchasing CFLs over incandescent bulbs, such as energy and cost savings as well as a longer lifespan. When experimenters made both the CFL and incandescent bulbs the same price ($0.50), nearly all participants (of all political stripes) purchased the CFL, regardless of whether it was explicitly labeled as "good for the environment" or left unlabeled. When the CFL was priced at three times that of the incandescent bulb (which reflects current pricing in the U.S.), conservatives and moderates were less likely to purchase the CFL when it was labeled as "good for the environment" than when it was not. Liberals showed no such difference. These findings suggest that more conservative individuals may forgo future cost savings to avoid projecting the image of an environmentally concerned citizen. Sociologists doing ethnographic work have similarly concluded that describing renewable technologies such as solar energy as "green" appears to limit the adoption of these products among political conservatives (Schelly, 2014).

"BOTTOM-UP" FACTORS: EGO, GROUP, AND SYSTEM JUSTIFICATION MOTIVATION

Why would exposure to the same information elicit divergent responses from liberals and conservatives? Recent work at the intersection of sociology, psychology, and political science has emphasized the role of "motivated reasoning" (e.g., Taber and Lodge, 2006). It may be useful to distinguish among three motives that can shape the processing of scientific (and other) information, namely (a) ego (or self) justification, (b) group justification, and (c) system justification (Jost et al., 2013).

For over 30 years, researchers have understood that individuals engage in "biased assimilation," so that they readily absorb new information that upholds the validity of their pre-existing beliefs and opinions while resisting new information that might challenge them (e.g., Lord et al., 1979; Ditto and Lopez, 1992). With respect to controversial political issues, Taber and Lodge (2006) demonstrated that citizens often exhibit "motivated skepticism"—using double standards to judge attitudinally incongruent arguments as weaker than attitudinally congruent arguments. This phenomenon might help to explain why respondents to Gallup surveys in 1990, 2000, and 2010 who felt that they understood the issue of climate change well were found to be more rather than less polarized in terms of environmental concern (Guber, 2013). Such ego-defensive tendencies, which are consistent with Festinger's (1957) cognitive dissonance theory, serve the goal of preserving the individual's self-esteem, insofar as it is easier to persist in the assumption that one's opinions are correct.

In many cases, it may be difficult to disentangle ego and group justification motives for processing information in a selective or distortive manner. This is because many cherished beliefs are linked to membership in a social group (Tajfel and Turner, 1986) or political party (Cohen, 2003) or cultural background (Kahan et al., 2012; Kahan, 2013). Thus, an experiment conducted by Hart and Nisbet (2012) demonstrated that exposure to scientific information increased support for climate mitigation policies among Democrats, whereas exposure to the same information decreased support among Republicans. Another experiment (conducted in Australia) revealed that increasing the cognitive salience of political identification caused "right-wing" individuals to express more skepticism about climate change (Unsworth and Fielding, 2014). Kahan et al. (2012) investigated the climate change attitudes of 1,540 U.S. citizens and observed that greater levels of scientific and mathematical competence predicted increased polarization, suggesting that individuals may have been using their cognitive resources to bolster their own pre-existing opinions or those of their political party rather than engaging in a process of learning and updating on the basis of exposure to new information.

According to system justification theory, people are not only motivated to defend and bolster the interests and esteem of their personal self-concept and the social groups to which they belong; they are also motivated to defend and bolster aspects of the social, economic, and political systems on which they depend (Jost et al., 2004). This motivation, which is more explicitly ideological than ego or group justification motivation, tends to favor conservative ways of thinking and behaving, insofar as it activates the goal to justify the status quo. At the same time, there are important situational and dispositional sources of variability in the strength of system justification motivation. Some individuals, for instance, are chronically higher than others in psychological needs to reduce uncertainty and threat, and they are generally more driven to maintain pre-existing institutions, traditions, and social arrangements (e.g., Jost et al., 2009; Hennes et al., 2012).

Studies show that conservatives are indeed more strongly motivated by system justification concerns (e.g., Jost et al., 2008; Vainio et al., 2014) and that ideological differences in economic system justification help to explain why conservatives are more skeptical about climate change and less supportive of environmental action, in comparison with liberals and moderates (Feygina et al., 2010; Campbell and Kay, 2014; Leviston and Walker, 2014). Consistent with these results, Lewandowsky et al. (2013) surveyed 1,377 visitors to climate blogs and observed that rejection of climate science was predicted by endorsement of free market ideology.

Likewise, nationally representative surveys conducted in Australia demonstrated that system justification in the economic domain was negatively associated with support for carbon pricing and other pro-environmental initiatives. Economic system justification was also associated with decreased moral engagement concerning environmental issues and—consistent with the "palliative function" of system justification—decreased negative affect concerning climate change (Leviston and Walker, 2014).

A study of university students in Finland revealed that perceptions of climate change as a threat to the national system and right-wing orientation predicted system justification in general as well as justification of the food distribution system in Finland. System justification, in turn, was associated with denial of anthropogenic climate change, decreased knowledge about climate-friendly food choices, and a decreased willingness to make climate-friendly food choices (Vainio et al., 2014).

Hennes et al. (2014) demonstrated that when system justification motivation was temporarily activated, participants exhibited biased memory for scientific information and greater skepticism about climate change. More specifically, when participants were made to feel especially dependent on the social and economic system, they were prone to underestimate the proportion of carbon emissions that were caused by human activity (as reported in a newspaper article they had read earlier in the session). It is worth emphasizing that the memory biases elicited by system justification motivation tended to minimize problems associated with climate change and exonerate the overarching socioeconomic system. Thus, an additional (and often underappreciated) factor contributing to motivated reasoning about climate change is system justification motivation.

CONCLUDING REMARKS

We have reviewed recent work in sociology, psychology, and political science that illuminates both "top-down" and "bottom-up" factors contributing to the ideological divide concerning climate change (see **Figure 1**). Although systematic research on this topic is only a few years old, there have been important advances. Institutional approaches emphasize the importance of "top-down" forms of elite communication, such as those related to corporate strategy, conservative think tanks, and mainstream media. Behavioral approaches focus on "bottom-up" processes, such as ego, group, and system justification motives, all of which are capable of contributing to polarization over climate change. We wish to point out that "top-down" and "bottom-up" factors are compatible and very often mutually reinforcing (see also Jost et al., 2009).

At the same time, it is clear that certain ways of framing messages are more effective than others when it comes to encouraging support for climate change policies (e.g., Feygina et al., 2010; Hardisty et al., 2010; Feinberg and Willer, 2011; Bain et al., 2012; Campbell and Kay, 2014). Johnson (2012) has argued that climate change communication is often ineffective because there is too much "fear messaging" and not enough "self-efficacy messaging," which encourages people to feel that they possess significant control over the situation. Fear messaging seems to increase recipients' needs for cognitive closure in general as well as their affinity for conservative labels and policies (Thórisdóttir and Jost, 2011), and conservatives tend to be more sensitive to threatening messages in the first place (Jost et al., 2003; Hibbing et al., 2014). Therefore, a little fear may go a long way, and it may induce citizens to respond defensively and engage in denial and minimization rather than facing up to environmental problems (Feygina et al., 2010; Jost and Hennes, 2013).

Nevertheless, focusing exclusively on message framing is likely to address proximate rather than ultimate causes of the ideological divide, which presumably include top-down, discursive structures as well as bottom-up, psychological functions. Few studies to date have isolated precise causal mechanisms linking political ideology to environmental attitudes and behaviors (but see Hennes et al., 2014, for an experimental attempt). We hope and anticipate that the demonstration of cause-effect relationships will become a higher priority in future research on the psychology of climate change. In the meantime, policy makers and concerned citizens will need to be more attentive to and effective in managing ideological processes and outcomes if the United States and other leading nations are to move beyond the present stalemate over climate change policy.

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Breaking down biocentrism: two distinct forms of moral concern for nature

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Why should deforestation be stopped? Why should greenhouse gas emissions be reduced? To answer moral queries such as these, one could point to the well-being of future generations and the survival of the human species. One could also appeal to the preservation of biodiversity and the intrinsic value of the natural world. These two attitudes are indeed distinct, and many scholars have therefore differentiated between "anthropocentric" (also called "homocentric" or "altruistic") and "biocentric" (also called "ecocentric" or "biospheric") concerns for the environment (e.g., Kahn and Friedman, 1995; Howe et al., 1996; Kahn, 1997, 2006; Schultz and Zelezny, 1998; Severson and Kahn, 2010; Hussar and Horvath, 2011; Steg and de Groot, 2012). Anthropocentric concerns for the environment are narrowly aimed at preserving the welfare of humans, while biocentric concerns are oriented toward protecting non-human organisms and nature as a whole. While anthropocentrism can sometimes lead to pro-environmental attitudes and actions, biocentrism is more reliably and robustly related to environmentalism, both for abstract values and for concrete behaviors (e.g., Gagnon Thompson and Barton, 1994; Schultz et al., 2005; Steg et al., 2005; de Groot and Steg, 2008). This makes sense, as anthropocentrism promotes the preservation of the environment as a means to an end rather than an end in itself. However, biocentrism treats environmentalism as a moral imperative independently of its impact on human flourishing.

In order to promote environmentalism, it is crucial to understand how moral intuitions can be made to resonate with values related to preserving the natural world (Markowitz and Shariff, 2012). Therefore, examining the psychological foundations of biocentrism promises to illuminate a path toward a more sustainable future. For this goal to be achieved, the idea of biocentrism must be deconstructed and operationalized in psychologically meaningful terms. In particular, biocentrism is unlikely to be a singular stance; rather, it plausibly consists of at least two qualitatively distinct attitudes. First, biocentrism can stem from a desire to *avoid hurting sentient beings* (e.g., harboring concerns about killing animals). Second, biocentrism can stem from a desire to *uphold purity* in nature (e.g., harboring concerns about violating the sanctity or telos of natural kinds). Avoiding harm and preserving purity have been identified as two separate forms of moral concern that rely on functionally distinct systems of cognitive and emotional processing (e.g., Rozin et al., 1999; Haidt and Joseph, 2004; Young and Saxe, 2011; Graham et al., 2013). Therefore, the concept of biocentrism potentially obscures a psychologically important distinction in environmentalist attitudes.

Subdividing biocentrism into two separate moral concerns—about harm and about purity—provides a meaningful starting point for investigating its psychological underpinnings (Rottman et al., in press). Understanding biocentrism in terms of avoiding harm emphasizes the importance of extending mental states and rights to non-human entities. In particular, the tendency toward anthropomorphization can enhance environmentalism because non-humans are conceptualized as possessing more humanlike minds, thus having a heightened capacity to be harmed (Waytz et al., 2010). Multiple studies have demonstrated that anthropomorphizing other species or nature as a whole increases biocentric beliefs and behaviors (e.g., Bastian et al., 2012; Butterfield et al., 2012; Tam et al., 2013). Additionally, taking the perspective of animals that are being harmed leads to greater biocentric concerns for the environment (Schultz, 2000). Biocentric concerns about harming nature therefore rest on expanded capacities for person perception and subjective ascriptions of others' suffering (Gray et al., 2012), such that the scope of justice is expanded to include non-human beings. In this way, biocentrism can arise from the same psychological processes that produce anthropocentrism; the only difference is that they are applied to a broader moral circle. This could explain why biocentrism and anthropocentrism are sometimes found to overlap (e.g., Stern and Dietz, 1994).

Alternatively, biocentrism is sometimes rooted in concerns about purity or sanctity. In particular, nature can be conceptualized as a divine creation that people have a sacred duty to preserve (Wardekker et al., 2009), and this sanctification of the planet has been shown to increase pro-environmental beliefs and behaviors (e.g., Tarakeshwar et al., 2001). This purity-based construal may be especially salient for particular populations. For example, framing environmental messages in terms of upholding the purity of the environment increases the pro-environmental attitudes of political conservatives, while harm-based framings do not exert any effect (Feinberg and Willer, 2013). Additionally, although this form of biocentrism is probably predominant in religious and spiritual individuals (Sherkat and Ellison, 2007), it is likely found in secular individuals as well. Indeed, sanctification often occurs outside of theistic settings (Pargament and Mahoney, 2005), and the treatment of certain aspects of nature as sacred may stem from a more general deontological tendency to harbor "protected values" (Baron and Spranca, 1997). Therefore, biocentrism is sometimes orthogonal to considerations about harm, arising from very different psychological processes than those that produce anthropocentric concerns.

In sum, biocentrism can be driven by at least two distinct moral concerns. When biocentrism is focused on avoiding harm, it is primarily geared toward protecting sentient and humanized entities, and it is likely moderated by individual differences in the tendency to anthropomorphize nature. Conversely, when biocentrism is focused on upholding the purity of the environment, it primarily operates at a more systemic level rather than focusing on the protection of discrete, individuated entities. Additionally, a purity-based biocentrism is likely moderated by individual differences in spirituality and in tendencies to treat certain objects as possessing inherent value. The psychological profiles underlying biocentric environmentalist attitudes due to harm concerns and due to purity concerns are therefore very different, although they might sometimes co-occur. Recognizing this distinction carries substantial implications for the efficacy of particular forms of environmentalist discourse (Rottman et al., in press). An adequate account of environmentalist attitudes requires that the construct of biocentrism is ultimately replaced by more nuanced distinctions. Understanding this aspect of human psychology will serve as a crucial step in putting an end to deforestation, greenhouse gas emissions, and countless other environmental threats.

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Some behavioral aspects of energy descent: how a biophysical psychology might help people transition through the lean times ahead

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We may soon face biophysical limits to perpetual growth. Energy supplies may tighten and then begin a long slow descent while defensive expenditures rise to address problems caused by past resource consumption. The outcome may be significant changes in daily routines at the individual and community level. It is difficult to know when this scenario might begin to unfold but it clearly would constitute a new behavioral context, one that the behavioral sciences least attends to. Even if one posits a less dramatic scenario, people may still need to make many urgent and perhaps unsettling transitions. And while a robust response would be needed, it is not at all clear what should be the details of that response. Since it is likely that no single response will fix things everywhere, for all people or for all time, it would be useful to conduct many social experiments. Indeed, a culture of small experiments should be fostered which, at the individual and small group level, can be described as behavioral entrepreneurship. This may have begun, hidden in plain sight, but more social experiments are needed. To be of help, it may be useful to both package behavioral insights in a way that is practitioner-oriented and grounded in biophysical trends and to propose a few key questions that need attention. This paper begins the process of developing a biophysical psychology, incomplete as it is at this early stage.

Keywords: biophysical psychology, environmental psychology, conservation psychology, energy descent, behavior change, prefamiliarization, embedded benefits, psychological well-being

INTRODUCTION

Since its beginning, the environmental movement has documented the declining state of the world. Stark language is used to catalog the many threats to the planet's natural systems and to the human settlements that depend on those systems. These deeply pessimistic outlooks continue to proliferate despite the fact that, when used alone, such accounts almost never increase concern or motivate action. Thankfully, there are also published inspirational stories—case studies of responses to environmental problems (Hertsgaard, 1999). There is no better antidote to social and environmental pessimism than Hawken's (2008) *Blessed Unrest.* Yet, if either the gloomy or the inspirational efforts had their desired effect then it might not be necessary to keep publishing quite so much on the topic.

This seems to call for a frank reassessment of our prospects starting with an update on the current context (Benson and Craig, 2014). The idea that context matters has long been embedded in the social sciences (Sommers, 2011). Yet, the changing biophysical context of everyday behavior has received little attention. It is not the goal of this paper to present another catalog of the downward spiral or to provide a selection of rousing success stories, although the importance of the latter is well-established. The intent is to show how a slowly changing biophysical context may be causing an entirely new behavioral context to emerge. Furthermore, the intended audience is not the general public but the many behavioral scientists and environmental practitioners who strive to better the world. The paper ends with several questions that might help direct research aimed at responding to the new behavioral context. From such research might emerge new approaches to helping people to live well while they live within ecological limits.

THE NEW BIOPHYSICAL CONTEXT

How ever vast were the resources used to create industrial civilization, they were never limitless. Biophysical constraints, always a part of human existence, could be ignored during these past few centuries, a unique era of resource abundance. This is no longer possible.

Many of the difficulties now being faced have their origins in a centuries-long consumption and construction binge and, soon, in its abrupt culmination. Both individual and collective behaviors have spawned multiple challenges, each now beginning to weaken industrial civilization. This is the premise of McKibben's (2010) book *Eaarth.* The world onto which we were born has been so disrupted that it's not the world on which we now live. McKibben (2010, p. 33) points out that, "We know, definitively, that the old planet "worked." That is, it produced and sustained a modern civilization. We don't know that about the new one."

These difficulties are manifestations of Harris's (1979) theory of cultural materialism which provides a scientific explanation for the ecological origins of civilization. Harris argues for the primacy of society's relationship with its environment—what he labels infrastructure and includes all forms of provisioning and supporting of daily life. Heinberg (2014, p. 5), in a superb synopsis, applies Harris' theory to emerging environmental circumstances and suggests that, ". . . we probably face an infrastructural transformation at least as significant as the Industrial Revolution." The reason why western industrial society may be on the verge of a major transition can be appreciated by reviewing the current natural resource and environmental situation.

ENERGY DESCENT

Western society may be challenged by the declining rate of extraction of global energy resources (Bardi, 2014) and in particular the liquid fossil fuels that are the lifeblood of industrial civilization (Hirsch et al., 2005; Princen et al., in press). The fossil fuels era, that period when fossil fuels came to dominate all other energy sources, began in the United states and worldwide as recently as the 1890s (Smil, 2011, 2012). This era is bounded by two unassailable facts—the planet's carbon stores are finite and the exponential growth in the use of these resources is unsustainable (Hubbert, 1996). But a sometimes overlooked issue here is not how much of a resource was once in place or now remains; but the geophysical limit on its rate of extraction.

For each reservoir of liquid fossil fuel, a maximum rate of extraction is eventually reached after which production plateaus, before an immutable decline. This limit to the rate of extraction is a matter of geology, not economics or technology or policy, a fact long understood by geologists but little appreciated by others. The maximum rate of oil production in the United States occurred in 1970 (Heinberg, 2012). The global on-shore peak occurred in 1984, Alaska's North Slope in 1989 and the North Sea in 1999. Over 60% of oil-producing countries have peaked or plateaued their rate of petroleum production.

One point of clarification about peak production is that it refers to the rate of extraction; it has nothing to do with the volume of the planet's energy stocks. And thus, despite a great deal of misinformation and misunderstanding, it is not about suddenly running out of fossil fuels. The peak in the production rate of petroleum typically happens near the point where half a reservoir's resource still remains. Given their enormous volume, fossil fuels will likely be extracted from the Earth's crust for years to come; what will decline is the amount available to society over any given time period. The concern here is the downslope from the peak rate of production, a psychologically unchartered territory.

Fortunately, the decline in the rate of production is often a slow, prolonged process. In the past, when a particular reservoir's production rate peaked, this slow decline provided the time needed to transition to new sources and develop new technologies. Previously, this adjustment occurred seamlessly, behind the scenes, as a normal part of the hydrocarbon exploration and development process. However, recently, as more reservoirs pass their peak extraction rate, this adjustment has become difficult, with one manifestation being the end of cheap energy (Campbell and Laherrère, 1998). Apparently, there are fewer high-quality sources whose production rate has not yet peaked. Now, the transition might need to be to realistic expectations and new patterns of end-use behavior.

The dynamics of the peaking of production rates at the global scale and the consequences of descending from that peak are being vigorously debated, albeit by a relatively small number of experts (Maugeri, 2004; Heinberg, 2007a,b; Hall and Day, 2009). The economic and political vulnerabilities are important (Kerschner et al., 2013) but so too are the social and psychological dynamics, yet the latter are only rarely explored (Frumkin et al., 2009; Friedrichs, 2010; Lambert and Lambert, 2011; Neff et al., 2011; Butler et al., 2012; De Young and Princen, 2012). The high emotions and huge stakes that play out in this debate (as well as the eerie political and media silence) make it hard for individuals and communities to form a coherent understanding or a timely behavioral response.

However, slowly, an agreement is emerging: industrial society is leaving the era of cheap and abundant energy; it will not return to it but for short respites. The global production rate of liquid fossil fuels soon may begin, or is already beginning, a drawn-out leveling and then slow descent, with other fuels and materials soon to follow the same pattern. Then industrial civilization, having already scoured the planet of new sources, will experience biophysical limits as a steady headwind against which it must labor. At that point will start, as Klare (2012) writes, a race for the little that is left. Indeed, that race may have already begun (IEA, 2014).

Thus, it might seem that a lively public discussion about the dynamics and timing of energy descent should be initiated. Yet, from a psychological point of view, exactly when these events begin is much less important than acknowledging that they will occur. In fact, given how essential material resources, and in particular energy flows, are to the smooth functioning of modern society, debating the exact timing might become a dangerous distraction. Certainly western nations should understand and acknowledge the biophysical limits they face but rather than dwell on the causes, it might be more useful to invoke the precautionary principle—what was previously referred to as common sense (i.e., a responsibility to help society protect itself from exposure to harm when systematic investigation identifies a plausible risk). The task would then be to construct and test affirmative responses to unfolding resource constraints.

NET ENERGY

It takes energy to get energy and transform it into socially usable forms. Maintaining a sufficient net surplus is what has become harder to do. This is due to declines in an ecological metric referred to as energy returned on energy invested (EROEI, sometimes EROI). This notion, also referred to as net energy, is the ratio of the amount of usable energy society acquires from a particular energy resource to the amount of energy it expends to obtain that energy. EROEI was first studied as the concept of net energy by White (1959), and particularly Odum (1973). It was developed by Hall (1972) in a biological context and later applied to the study of biophysical economics (Cleveland et al., 1984) and energy systems (Cleveland, 2005; Hall, 2011, 2012).

Energy returned on energy invested is hardly ever used in policy-making, dominated as the latter is by economistic reasoning. This history, and the simplicity of the concept itself, should not distract from its profound implications and future utility. The metaphor of low-hanging fruit can be used to explain the notion from a decision-making perspective. Extraction occurs first at the more attractive opportunities in easy to reach, hospitable regions containing high-quality resources (e.g., uncontaminated, high density) near the surface which thus makes them easy to extract, process and transport. Later, the resources are sought in inhospitable locations (e.g., offshore, deep-water, arctic, dangerous) and are of lower quality, thus becoming much harder to recover, refine and deliver. Harder here means the need to employ more equipment, larger systems and complicated logistics, all of which themselves consume energy during their lifecycle. For instance, many of the newer unconventional energy sources require advanced technologies, massive capital investment and, most significantly, increased amounts of energy which from a thermodynamic perspective is the ultimate determinant of net energy availability.

This pattern—pursue the easiest to get first and the more difficult to obtain later—while a perfectly sensible decision economically and technologically, means that over time the net energy available to society inevitably declines. Perhaps this would be nothing more than an interesting story for technocrats except that *now is later*. We are at the part of the story where there is less and less net energy with which to operate society. Political scientist Homer-Dixon (2006) argues that just such a declining EROEI was one factor underlying the collapse of the Western Roman Empire in the fifth century CE. Tainter (1988) presents the complementary idea of diminishing marginal returns of societal complexity to explain the decline of that and numerous other civilizations, and then goes on to apply this concept to contemporary civilization (Tainter, 2000, 2006, 2011, 2013).

At the beginning of the petroleum era the EROEI ratio was extremely high. The initial massive surplus of net energy may have misled society with the false prospect of endless physical growth. False because, while it went unnoticed, net energy has been on a relentless decline (Hall, 2012). Certainly, when the EROEI ratio of an energy source is less than one then that source becomes an energy sink and is useless to society as a means of maintenance, let alone growth. That a vast store of the Earth's fossil carbon could become an energy sink is not an outlandish idea. Heinberg (2007b) reports that a large amount of the coal remaining underground will require more energy to extract than it will produce when burnt, thus becoming an energy sink rather than an energy source.

The question of what minimum EROEI is needed to support a complex society has been considered by Hall et al. (2009, 2014), Guilford et al. (2011), Hall (2011, 2012), Lambert and Lambert (2011), and Lambert et al. (2013, 2014). In this analysis it matters tremendously what features of society are believed to be necessary or desirable. As the services included in the definition increase, so too does the EROEI ratio needed to support that society.

Most often the EROEI ratio is calculated upstream at the well- or mine-head and includes only those energy costs directly related to the hydrocarbon exploration and production process. In an effort to make the EROEI concept more useful for social decision-making, Hall et al. (2009) and Hall and Klitgaard (2012) have expanded the methodology to also account for the many indirect energy costs experienced when providing services to society (e.g., the energy costs of transport, infrastructure, manufacturing, provisioning, maintenance). This is the net energy downstream, near the point of end-user consumption, and is reported as the extended-EROEI ratio.

A 3:1 extended-EROEI ratio is considered the "bare minimum for civilization" (Hall et al., 2009, p. 45; Hall and Klitgaard, 2012, pp. 318–319). Although at such a level modern society would lack the surplus energy needed to support most of the higher-level services that it has come to expect. In Western society, more than the most basic provisioning would require an extended-EROEI ratio of about 7 or 8:1, adding basic education would require a ratio closer to 9 or 10:1, health care and higher education would require a ratio near 12:1 and the arts and other noble pursuits push the required ratio even higher (Hall and Klitgaard, 2012; Lambert et al., 2013). Dadeby (2012) applied the extended-EROEI methodology to global production data and estimates that the current global ratio is at 6:1. Equally concerning is that most alternative, unconventional and biologically based sources of energy also have very low ratios.

A similar analysis can be applied to food production. The United States food system, as a result of the juggernaut of industrialization, consumes the vast majority of the energy it utilizes in post-farm processing, distribution and household preparation. Based on 2002 USDA data, the United States now invests over 12 calories of energy for each calorie of food consumed once waste and spoilage are accounted for. Of these, only 1.6 calories are used on the farm (Canning et al., 2010). This analysis suggests that industrial food production is unsustainable without fossil fuel inputs.

As the overall EROEI declines, society has less and less net energy to use for its needs as an ever-increasing percentage of the extracted energy is consumed by the hydrocarbon exploration and production industry itself. The day may be approaching when the surplus net energy from conventional and unconventional hydrocarbon sources becomes insufficient for maintaining, let alone building out, complex industrial society or the much hoped for renewable energy systems. Furthermore, if there is not enough surplus net energy to respond effectively to the many environmental issues being faced then a reallocation away from discretionary uses may be unavoidable. Taken together, this poses a psychological challenge: how might people, individually and collectively, respond to a substantial decline in discretionary resource use?

TECHNOLOGY

It is here that technology is commonly invoked as a solution. It has become a habit to celebrate modern technical ingenuity, and in fact its application has produced innovations that have propelled dramatic and absolute increases in material well-being. This leads many people to be extremely optimistic, even complacent, about finding technological solutions to all problems challenging society. This is a dominant outlook, what has been called the industrial progressive worldview (Princen et al., in press). But there is reason to be less optimistic and certainly not complacent (Costanza, 2000; Alexander, 2014).

The great bulk of inventiveness has been aimed at increasing efficiency in all the many stages of material and energy extraction, conversion, use and reuse. But initial efficiency gains are the easiest to attain—they are the proverbial low-hanging fruit—after which the law of diminishing returns makes further improvements ever more difficult to achieve. Butler et al. (2012) point out that while efficiency-driven approaches have great potential they can never keep up with exponential growth in the use of materials or energy.

There is a behavioral side story here. Some energy-efficient technologies have paradoxically contributed to an increase in resource use (e.g., energy-efficient light bulbs actually increase electrical consumption when it seems justified to install them in greater numbers to provide increased illumination). This rebound effect is well documented (Hofstetter et al., 2006; Hanley et al., 2009; Madlener and Alcott, 2009; Norgard, 2009; Otto et al., 2014) but Princen (2005) has expanded on its implications by explaining how efficiency-driven modernization has misled us, and calling for a shift toward a logic of sufficiency.

Overall, despite a century of technological progress that provided noteworthy efficiency gains and innovations in design, policy and practice, there has been not the expected decrease but an absolute increase in aggregate natural resource consumption (Princen, 2005). Whether this is incorrectly attributed solely to population growth, or it is correctly noted that per capita consumption has also grown, the negative environmental outcomes remain unchanged. Society may be experiencing the unwelcome consequences of having used its technological ingenuity to attempt limitless growth on a finite planet.

But there is another and more fundamental reason to worry about whether technology can be an aid in dealing with energy descent. The technological foundation for an industrial society (e.g., logic and mathematics, physics, chemistry, engineering) and even the demonstration of advanced concepts and devices all existed for a great many centuries. But the available energy sources of muscle, biomass, water- and wind-power were unable to provide the energy quantity or quality needed to support an industrial revolution. It took the discovery and large-scale extraction of fossil fuel energy to enable the building of an industrial civilization. Simply put, the process of technological modernization was energy limited not knowledge limited. As Greer (2012, p. 97) points out, "It's as arrogant as it is silly to insist that people in past ages weren't as resourceful and ingenious as we are." Thus, while technical cleverness is credited with creating a vibrant industrial society, and it is hoped that its continued application will solve all forthcoming problems, history suggests that it was instead a one-time gift of resource abundance that got us here. After all, inspired technologies cannot create energy and industrial prowess cannot negate the laws of thermodynamics, they can only transform finite energy and material resources into forms useful to society.

Nonetheless, boosters will claim that new technologies are unleashing vast amounts of energy from new sources, as, for instance the assertion that the recent innovation of hydraulic fracturing is releasing natural gas and light tight oil from new formations. What may go unnoticed is that neither the technology nor the low-permeability formations being mentioned are new; both have been long known to the hydrocarbon industry. What make feasible such extraction are the high fossil fuel prices that allow the use of previously prohibitively expensive technologies. But even this process of alchemic transformation may reach a limit. Research suggests that, to sustain urban growth, technical and social innovations must emerge at a continually accelerating rate (Bettencourt et al., 2007). Yet, requiring that individuals and organizations invent and adapt at an exponential rate in order to avoid stagnation and eventual collapse quickly reaches a limit; exponential growth in any process is, after all, unsustainable.

The end of resource abundance may require that techno-optimism be tempered since energy descent will make the effectiveness of technology that much lower. And while technical skill will be frequently called upon, the most that might be expected from it is to slow the approach of a resource-limited future; technology cannot fundamentally change that outcome.

THE NEW BEHAVIORAL CONTEXT

Previously, when growth was an easy thing to do, it was possible to disregard the biophysical foundation of civilization. During a relatively brief period of material affluence behavioral scientists could focus on social and psychological needs unhindered by natural resource constraints. Later, as ecological limits were first anticipated (Meadows et al., 1972) and then became apparent (Meadows et al., 2004; Bardi, 2011), some among us advocated for the study of conservation behavior (Daly, 1977; Stern and Kirkpatrick, 1977; Henion and Kinnear, 1979; Cone and Hayes, 1980; Cook and Berrenberg, 1981; Stern and Gardner, 1981). This was followed by decades of environmental and conservation psychology research that has led to an explosion of insights on theories of social change and intervention guidelines for promoting environmental stewardship behavior (Clayton and Myers, 2009; Clayton, 2012; De Young, 2013).

Earlier, it seemed that the major task facing modern society was to create a shared vision of a sustainable society providing a permanent prosperity lived within ecological constraints (Costanza, 2000). The changing biophysical context may foreshadow a less optimistic outcome and it certainly foreshadows a more difficult social transition. One reason for this is that the earlier behavioral context assumed that a consumer-focused, industrial society *could* be made sustainable. The observations above—that the rate of energy and material production may soon plateau and then decline, and that technological innovation may help ease a societal transition but will not eliminate the need for one—brings that prospect into question. It is at least conceivable that society soon will face the biophysical situation just outlined and need to learn to function within a newer, perhaps more austere, behavioral context. In an effort to aid this transition it might be useful to merge insights from across the social sciences into a biophysical psychology.

A TRANSITION, NOT A PROBLEM SOLVED

Re-emerging biophysical constraints are not problems, at least not in the normal definition of that word. They are complex ecological predicaments, unsolvable situations that likely will play out over the rest of this century and the next. As Greer (2008) points out, we approach a problem by looking for a solution, if one is found and can be made to work then the problem is solved. In contrast, complex predicaments do not have solutions, they must be endured (Smith, 2014). Certainly, in order to thrive, we must acknowledge and respond to them, but even an effective response does not make the predicament go away. The response does not alter but rather accommodates the new reality. This is adaptation in its classic usage: to recast or change behavior patterns into new forms so as to fit the new ecological situation.

Furthermore, biophysical limits present behavioral challenges that are unlike those of emergencies and crises. The needed responses might be better characterized as transitions, processes that differ from an emergency or crisis in the depth of change required, the time frame involved and the prospects about the future (Princen, 2014). An emergency is immediate, with a central precipitating event calling for a rapid and focused reaction designed to restore life to the condition before the emergency. A fire consumes, prompting reaction and rebuilding, after which life resumes as before. Likewise, a crisis unfolds over months and years, and although it may resist a complete resolution, with recovery and remediation there is eventually a return to business-as-usual. The oil shocks in the 1970s created a crisis among the industrialized nations, stalling consumer spending and thus economic growth. But with new policies and behaviors (e.g., strategic petroleum reserves, residential energy conservation) and a shift to other energy sources, industrial activity ever-so-slowly returned to growth.

It may be possible to analyze an energy descent as a crisis, at least in its very early stages. Lambert and Lambert (2011) have anticipated a crisis response by the American people to declining EROEI by examining the resulting individual and social-system stress as well as the coping mechanisms employed and the resulting institutional effects (see also Hobföll, 1989). Then again, in a transition, the trajectory may be fundamentally different. The triggering issues are likely complex and may involve multiple interacting events (i.e., simultaneous geopolitical instability, energy descent and climate disruption). The effects may be broadly spread over physical and social systems, very slow to emerge and even slower to be widely acknowledged. The resulting changes, and the response to them, can span decades, entire lifetimes, even centuries. Suffice it to say that in an emergency or crisis the intention is to weather the storm and "get back to normal." Whereas in transition it is understood by the leaders and public alike that there is no possibility of going back, the intent is to "get to a new normal." Behaviors in an emergency or crisis are reaction and recovery; in transition they are innovation and adaptation.

Moreover, in a transition, the responses likely would need to be maintained and periodically updated over a lengthy period. Unfortunately, society has little familiarity with the long-drawn-out planning and management needed to respond well to biophysical limits. For while social institutions and individual behaviors exist for handling a comparatively brief emergency or crisis, and while changes that occur exceedingly slowly over a period of centuries rightfully can be left to the process of normal social adjustment, there exists little guidance for the mid-range, a many decade- or century-long transition. Parts of a science of such mid-range transformations are being developed. For instance, a psychology of prospection is emerging and will be useful to long-drawn transitions (Seligman et al., 2013). Navigating long timeframes can be difficult. The effects of behaviors changed today might only be appreciated in 80 years' time. This lag has the potential to undermine motivation. Or, in a more positive framing, we must understand the conditions under which long-term planning is possible (Princen, 2009) and discover those situations where a lag between cause and effect does not undermine motivation but, perhaps unexpectedly, strengthens it.

Such an extended behavioral timeframe is inherent in the wedges concept proposed for keeping carbon emissions in check. Here, instead of searching for a single large-scale solution, Pacala and Socolow (2004) note that a number of smaller options already exist for reducing our collective environmental impact. They propose breaking the required changes down into manageable wedges each addressed by a different existing technology or policy. This idea has a behavioral version whereby over one third of the needed reductions can be accomplished by currently understood changes in everyday household activities (Dietz et al., 2009).

Yet, when viewed as a century-long process of behavior change, two significant issues emerge. The technological and behavioral wedges adopted early on must stay adopted, perhaps difficult in a world seemingly addicted to frenetic change and social reinvention. This needed durability presents an intervention challenge since the behavioral sciences are only starting to understand how to initiate robust self-sustaining and/or easily restarted behavior change (De Young, 2000, 2011; Abrahamse et al., 2005; Werner, 2013). Equally challenging is that to stabilize the positive outcomes, each wedge adopted must expand over time. Since the early changes do not solve the problem, there is a need to constantly innovate and adopt new behaviors and policies. While the near-term changes involve the adoption of currently known approaches (e.g., green consumer behaviors, efficiency-focused policies), changes a few decades hence can scarcely be imagined. Behavioral scientists acknowledge this difficulty by stating that later on, "[l]ifestyle changes may become necessary in the out-years under constrained energy supply or economic growth scenarios . . . " (Dietz et al., 2009, p. 18455).

But to label these needed future responses as "lifestyle changes" may mislead in two ways. First, the term itself would seem to imply that gentle and slight changes in daily habits will suffice. Yet, shifting consumer and living habits toward more green choices might prove to be a totally insufficient response should the biophysical events unfold as outlined above. Second, near the end of this century, day-to-day behavior patterns will need to consume nearly an order-of-magnitude less energy and materials than are currently used. The environmental movement has previously argued for major reductions in resource consumption but rarely have changes of this magnitude been envisioned.

It is not at all clear that the general outline, let alone the details, of these future behaviors are now known. It is difficult to imagine what daily life might be like after such a drastic reduction in resource consumption. Certainly it is possible to live at such a low-energy and material flux, indeed almost all of human history occurred within a pre-industrial low-energy context. But what is not known is how to live at such an austere level while still enjoying the comforts and conveniences afforded by industrial society. Frankly, it may not be possible for members of Western societies to maintain anything close to a contemporary life pattern while also living within the new biophysical context. If this proves to be the case, then the responsibility of behavioral scientists is to now explore and then prepare people for the social and psychological implications of that realization. At a most basic level, many people will grieve from losing an affluent lifestyle or from losing the belief that material growth will one day provide for such an existence. If nothing else can be accomplished, then it will be praiseworthy to help people cope throughout this transition, to help them to function better than they would otherwise.

There is interesting work along this line that explores the effects of energy descent on public health (Frumkin et al., 2009; Neff et al., 2011; Poland et al., 2011) and societal-level quality-of-life indicators (Lambert et al., 2014). Likewise, the possible mental, physical and community health impacts of other forms of environmental disruption are being mapped out; potentially useful are the guidelines on how communities can prepare for the psychological impacts of such disruption (Doherty and Clayton, 2011; Reser and Swim, 2011; Clayton et al., 2014). Similar efforts are needed to prepare individuals and communities for the dramatic yet long-drawn-out social and psychological impacts of energy descent and declining net energy.

Perhaps an affirmative outcome is possible. If handled well, an energy descent could be an opportunity to bring out the best in people (Baker, 2011). This potential was earlier suggested by Hubbert (1996) who analyzed the decline in fossil fuel production rates. Hubbert (1996, p. 126) suggests that if action is taken before the situation becomes unmanageable then, "there is promise that we could be on the threshold of achieving one of the greatest intellectual and cultural advances in human history." Notice that instead of using wording like stress, disintegration or collapse, Hubbert (1996) envisions a response to biophysical limits as an advance. It is here that the behavioral sciences might be of most use by helping people facing a changing biophysical context to craft new visions of their future, identify new behavior patterns, acquire and share the required skills and motivate the venture. But it is important to start the process while there are still options and surpluses of energy and social capital.

NOT JUST ANOTHER APPLICATION AREA

Henry David Thoreau famously asked, "What's the use of a fine house if you haven't got a tolerable planet to put it on?" (Sanborn, 1894). This same logic—that some things are foundational and must be treated as such—might be applied to the current topic. All through the last century, when cheap energy was available in ever-increasing amounts, the behavioral sciences treated biophysical limits—when thought about at all—as an economic or technological issue more suitably addressed by other disciplines. Such inattentiveness was supported with the widespread assumption that unlimited growth could continue and not adversely affect the earth's ecosystem—what Daly calls "empty world" thinking (Daly and Farley, 2010). Later, when ecological constraints were finally acknowledged, the behavioral effects and interactions were taken up primarily by sub-disciplines such as environmental and conservation psychology (De Young, 2013). This tendency to specialize the servicing of social needs has been commonplace and generally effective. But it is important to note that the growth and ubiquity of specialization may itself have been made possible by an era of large and predictable surpluses of net energy. Absent those surpluses it may be difficult to continue such an approach.

Stated plainly, helping society to thrive while living within ecological limits should no longer be treated as just another application area of the behavioral sciences. Responding to biophysical constraints has become an existential issue, global in scope, local in impact. Whatever social good can be achieved through the application of empirical discoveries and clinical practices, that good may remain unrealized should society falter in its response to energy descent. Thus, developing a biophysical psychology is an essential pre-condition for attaining the other worthy goals of all social scientists and practitioners.

Ironically, just as it once proved easy to relegate biophysical limits, psychology itself has been ignored by the energy descent community, except occasionally as an instrument for "getting people to behave right." The real action was argued to be in the physical and policy sciences. Sometimes this dismissal comes from the perspective that since most environmental problems originate from individual behavior (i.e., the sovereign consumer), people cannot be counted on to voluntarily make things right. Other times the negation emerges when behavioral interventions are being compared with other non-behavioral approaches. To present just one example, Newton (2014), in a discussion of energy-efficient neighborhoods, compares technological intervention and voluntary behavior change to sustainable urban design, the latter being that paper's focus. Despite highlighting the potential for rapid change at low public costs, behavior change is dismissed as being unable to scale-up and spread quickly enough to make a difference. Note, however, that the modifier being used here is voluntary; in the absence of an outside force or precipitating event, so the argument goes, behavior is unlikely to voluntarily change sufficiently. This is a critique that is taken up shortly.

While it is not appropriate to arrogate to the behavioral sciences a special role in forming a response to biophysical limits, it can be noted that, under certain conditions human behavior can innovate quickly and that the behavioral sciences understand those conditions. Furthermore, human nature is not just a source of the problems being faced but also a fount of solutions awaiting dissemination. Indeed, seeking interventions that help craft a better world is a centuries-old quest that cuts across all the social sciences. This would seem to call for broad involvement in forming a biophysical psychology. It echoes the assertion of the American Psychological Association that research addressing climate change cannot be left to just one sub-discipline but must utilize the expertise of researchers and practitioners from multiple areas (Swim et al., 2009). Thus, rather than dismissing behavioral interventions as an ineffective response, many empirical findings from a variety of academic disciplines support the decidedly optimistic view that individual behavior can change in timely, profound and durable ways (Clayton and Myers, 2009; Basu et al., 2014; Kaplan and Basu, in press) and the behavioral sciences know how to help initiate and then support this process of social change.

SIMPLIFICATION OF BEHAVIOR CHANGE

Early on it was imagined that since more than 70% of what an industrial nation produces is for personal use, encouraging green consumption would be a direct means of achieving environmental sustainability. Thus, behavioral science focused on encouraging green consumerism, a belief that by modifying consumption choices it would be possible to "green and lean" industrial society enough to create an ecological steady-state. This approach drew from the many interventions used to change behavior (De Young, 1993, 2011; Stern, 2000; Abrahamse et al., 2005; Steg and Vlek, 2009; Osbaldiston and Schott, 2012; Steg and Nordlund, 2012). The goal here was to inform, motivate and guide behavior but always with the understanding that behavior change was ultimately voluntary. Rarely was it proposed to directly coerce or restrain consumer choice. Such restrictions, when applied, were usually upstream in the industrial design and production process. Moreover, these restrictions were most often efficiency-driven efforts that affected consumer choice only indirectly (e.g., CAFE standards, EnergyStar appliances) and were usually slow-acting.

Green consumerism is an approach fully compatible with the principle of voluntary behavior change. It poses no threat to business-as-usual within industrial society where consumers are to be treated as sovereign and their purchasing behavior is to remain inviolate (Princen et al., 2002; Princen, 2010). Green consumerism is also a gentle approach because it contains the implicit promise that after achieving a sustainable state, the comforts and conveniences of modernity will remain as would the belief that such a lifestyle could be made available to everyone on the planet.

Unfortunately, despite enlightened efforts at green marketing, environmental education, sustainable design and environmental policy-making, the consumerist life pattern continues to consume the planet. In fact, decades of education and intervention have produced not decline but growth in industrial society's ecological footprint (Rees, 2010). One could argue that without these interventions, and the behaviors they changed, things now would be much worse. But despite the truth of that statement, humans continue to overshoot the planet's carrying capacity (Catton, 1982; Turner, 2012) in part because green consumption does not necessarily mean less consumption (Jackson, 2005).

If these prospects are not attention-getting enough, the approaching biophysical limits expose another realization. Underlying the commendable principle of voluntary behavior change is a key supposition. It presumes that circumstances permit people the choice either to continue consuming or to reduce their consumption. Yet, given the biophysical context outlined above, this presumption may no longer be valid. This is what sustainability at its core is about—behaviors that are or become unsustainable will end.

Thus, soon now, whether due to energy descent, declining net energy or some other ecological limit, modern society likely will be consuming less, ready or not. A reduced-consumption existence may become commonplace not because conservation behavior was voluntarily chosen by the public or cleverly initiated by behavioral scientists but because there will be no other choice. Having ignored many opportunities for voluntary simplicity (Gregg, 1936), industrial society now faces involuntary simplicity. It will consume less because there will be less to consume. Dire consequences will still arise from past consumption and its delayed consequences (e.g., drawdown of fossil aquifers, loss of soil fertility, ocean acidification, climate disruption) but future consumption will first slow then decline.

This feature of the new behavioral context, what might be called behavioral simplification, unexpectedly may make the process of transitioning easier. First, the downshift most likely will be slow. As Greer (2012, pp. 97–98) points out, "The resource base of industrial society is shrinking but it's far from exhausted, the impact of global warming and ecological degradation build slowly over time ... " This is not at all what the popular folk mythology of resource apocalypse predicts. It lacks Hollywood's sudden and catastrophic collapse motif. The change is more likely to emerge slowly over decades—a persistent step-wise downshift to a new normal.

Yet, there are still behavioral challenges to be addressed if this downshift is to be experienced more gently than it might otherwise be. Modern society, as a whole, does not have a settled pattern of voluntarily exploring and adopting alternative life patterns in advance of being forced into so doing. In fact, there is ample evidence that whatever resources were available were consumed to the point of overshoot (Catton, 1982). What behavior change successes there have been all too often are followed by a return to previous consumerist tendencies once the initiating event subsides. Such experiences might leave people with the sense that an effective strategy is to wait out the apparent crisis and anticipate a return to normal.

The rest of this paper recommends an agenda for helping the development of new living patterns before such major adaptations are forced upon society. One issue here involves the choice of how to assess the prospects of responding in time to energy descent. Another is the need to acknowledge that the behavioral and social sciences may not be in charge of the ensuing response. Meadows et al. (2004, p. 284) faced the first issue and framed it as a choice among three prospects:

> ". . . the world faces not a preordained future, but a choice. The choice is between different mental models, which lead logically to different scenarios. One mental model says that this world for all practical purposes has no limits. Choosing that mental model will encourage extractive business as usual and take the human economy even further beyond the limits, the result will be collapse.
>
> Another mental model says that the limits are real and close, and that there is not enough time, and that people cannot be moderate or responsible or compassionate. At least not in time. That model is self-fulfilling. If the world's people choose to believe it, they will be proven right. The result will be collapse.
>
> A third mental model says that the limits are real and close and in some cases below our current levels of throughput. But there is just enough time, with no time to waste. There is just enough energy, enough material, enough money, enough environmental resilience, and enough human virtue to bring about a planned reduction in the ecological footprint of humankind: a sustainability revolution to a much better world for the vast majority.
>
> That third scenario might very well be wrong. But the evidence we have seen, from world data to global computer models, suggests that it could conceivably be made right. There is no way of knowing for sure, other than to try it."

Their perspective is a guarded optimism to be sure. But for the issue at hand—shifting behavior patterns to those compatible with biophysical reality—it is particularly fortunate that the patterns that people may need to adopt are not totally without precedent. As Boulding (1978, p. 93) once quipped, "Anything that exists is possible." The needed patterns are neither new nor untested nor absent from the world at large; what they are is unfamiliar and perhaps unwelcomed by most members of industrial society. But change need not start all-at-once in every corner and with every member of society, indeed it rarely does.

Early experimentation with simple living is recorded in the history of intentional communities in North America (Kanter, 1972; Morris, 2007). A few of these continue to exist, most often as living museums but occasionally as growing communities (e.g., Amish). There also are modern social experiments involving early adopters who are exploring changes to deeply ingrained life patterns. Some are approaches derived from Lewin's (1952) pioneering work on using citizen assemblies to affect radical change by first presenting people with the issue being faced and then giving them the trust, time and support needed to develop local responses. A useful update of this method, focused on environmental stewardship, was done by Matthies and Kromker (2000). Several examples, relevant to but not directly addressing energy descent, employ a community-based intervention called EcoTeams (Staats et al., 2004; Nye and Burgess, 2008). These include changing a broad collection of behaviors but center on the household or neighborhood scale and usually focus on consumer behavior.

Some fascinating examples that directly address energy descent and are being implemented at a somewhat larger scale include ecovillages (Liftin, 2011, 2012, 2013a,b) and transition towns (Hopkins, 2008, 2011; Chamberlin, 2009). There is great variation across these settlements but they seem to have in common a focus on environmental and social stewardship. What is fascinating is that these latter explorations were not initiated nor supported by the behavioral or social sciences, corporations, governments or the major non-governmental organizations; they self-initiated. Some of them are being chronicled by scholars but empirical research on their evolution has only just begun (see, for instance[1]).

Perhaps more important than their appeal to the pioneers is the potential for these social experiments to serve as models for other, later adopters. It seems likely that many people will decide to change only after signs of an energy descent become overwhelmingly clear to them. Fortunately for these late adopters, each step down the energy descent, as unnerving as it may be, will likely be followed by relatively stable periods. It may be reasonable to expect the periods in-between each downshift to be stable enough to allow time for exploring and experimenting with alternative life patterns. These intervals also may provide the time needed to build resilience into social and community systems and thus allow these systems to better deal with the next ecological or societal step down (Alexander, 2012).

Although the descent may be slow and punctuated, it likely will be relentless. Early on, each drop may seem like an emergency or crisis making it possible to expect that, with time, things may return to normal. But slowly, every next downshift, coupled with the unknowable duration of each pause, will make such an expectation untenable. Instead, over time, a growing number of people will experience biophysical constraints as unavoidable, directly perceivable and palpable. The need to change behavior would become blatantly obvious. Denial occasionally might be possible, perhaps prompted by the slow descent and stable lulls. But with every next step down an ever growing number of people would find delay to be a non-functional response, maybe even a personally perilous one.

Thus, the long-drawn nature of the descent, with interludes supportive of social experiments, may make behavior change easier. Practitioners and educators may no longer need to persuade people to change but instead would need to be ready to help them to do so. No longer would the public need to judge the veracity of abstract notions of limits-to-growth. Under the signals of an emerging energy descent, the process of societal transition and individual behavior change would not await professional intervention, governmental permission or venture capital support. It would self-initiate—although, perhaps initially, hidden in plain sight.

PROSPECTING THE COMING TRANSITION

If the biophysical situation and the resulting change in the behavioral context unfold as just outlined then modern society will face an involuntary transition of unprecedented depth and duration. Prefiguring a variety of responses might make for an easier transition. The process of crafting a response may also contain some fascinating opportunities. But getting people to this realization cannot be achieved just by laying out the facts of a potential energy descent. After all, presenting such threats-of-change in the past has rarely prompted environmental stewardship behavior. If that approach had worked as well as needed then society might not be facing the current predicament. And although we may be facing a future of slow regress rather than rapid progress, "regress is quite literally an unthinkable concept these days" (Greer, 2012, p. 99). Thus, taking a direct, facts-first approach has virtually no chance of easing the transition, particularly when the context is not a solvable problem but a complicated predicament.

If we paused for a moment, and reflected on this social dilemma, it might be easy to despair of the human prospect. Yet the issue here may be one of mis-framing and thus lends itself to re-framing. An approach that might have promise is to help people to slowly build their own understanding of the newly emerging biophysical context while simultaneously helping them to explore behaviors that are meaningful to them now, while also pre-familiarizing them with behaviors that might be essential further on.

THE USEFULNESS OF SMALL EXPERIMENTS

Behavior change under conditions of urgency, great environmental uncertainty and grave stakes might be advised to start with small steps. As anthropologist and political scientist Scott (1998, p. 345) advises with respect to interventions for economic development, "Prefer wherever possible to take a small step, stand back, observe, and then plan the next small move." Scott's (1998) suggestion follows, in part, the "small experiment"

[1] www.transitionemergingstudy.ca

approach to environmental problem-solving outlined by Kaplan (1996; see also Kaplan et al., 1998; Irvine and Kaplan, 2001). Small experiments are a framework for supporting problem-solving that is based on people's innate inclinations to explore and understand (Kaplan and Kaplan, 2003, 2009) and on their brain having evolved to prospect the future not just track the past (Seligman et al., 2013). The small experiment approach also supports behavioral innovation, maintains local relevance and experimental validity, all while promoting rapid dissemination of findings. It also contrasts with the large-scale approach that dominates research these days. This framework can help people who are not trained as scientists to discover what works in their locality.

To enhance engagement, the small experiment framework carefully manages the scale of the activity. Picking the appropriate scale is a crucial step. It was Weick's (1984) insight that people anchor around the scale and structure of the initial problem definition and start to work on responses that are only at that same scale or structure. If we cast the problems faced as being at a large-scale or involving large systems, as is often the case with environmental issues, then it is hard to imagine anything but a large-scale or large system response sufficing. Fortunately, although large-scale problems may seem to demand large-scale responses, the scale of the problem does not dictate the scale of the response.

Small experiments are going on all the time. They are often the basis of stories told by at-home tinkerers, dedicated gardeners, community organizers, and innovative teachers. They are part of team efforts where experts and citizens coordinate and apply their talents and knowledge to an issue of mutual concern. Consider the many pilot programs, demonstration sites, field tests, and trial runs regularly reported in both popular and scientific publications, as well as the neighborhood, community, and village examples mentioned earlier. In fact, small experiments are so common that they may seem inconsequential to the casual observer; nevertheless they can be a powerful means of behavioral entrepreneurship. Despite their ubiquity, Kaplan (1996) and Irvine and Kaplan (2001) have discussed guidelines for enhancing the effectiveness of small experiments and broadening their appeal beyond just early adopters. Very briefly summarized, these are:

Scale
While already an integral aspect of small experiments, smallness can be understood in a variety of ways. Keeping the physical scope small is obvious. Others include keeping the time-span short and the breadth of exploring restricted as well as involving only a small number of people. The experiment can also be tentative, tried out for a limited time. These guidelines help keep the costs of project initiation and management low.

Expectations
So too should expectations be kept in check. The findings of small experiments are unavoidably imperfect and incomplete. Yet small too are the consequences of failure; failure is always a possibility if an experiment is genuine. Even so, findings from a modest enterprise may prove extraordinarily useful and have broad effects.

Goal and focus
An energy descent would be felt in all parts of society and affect all daily activities. Nevertheless, it is useful to keep the focus of the small experiment on only one specific issue. While it may be okay to start exploring before having everything in place, it is essential to first have a concise question. Anticipating what would be most useful to be able to say at the end is an excellent way of formulating the initial question.

Tracking and record keeping
Empirical research, at its core, involves being attentive to what is going on. Whether formal or informal information gathering is used, the objective is to systematically learn what worked and what did not. In the immediate timeframe and at the local level, the tracking allows for feedback to those directly engaged. Over a longer timeframe, it informs next steps and may provide the basis for developing generalizations that might be useful elsewhere.

Dissemination and communication
Sharing the successes of a small experiment is a way to let the people involved knows that their efforts matter. It is also an opportunity to validate the correctness of the proposed changes for the community members who were not engaged in the effort. Finally, communicating with people at a distance may provide credibility to other small experiments and help to motivate and support the efforts of later adopters; successes in one locality become plausible options to explore elsewhere, while communicating about failures instills caution and may prevent wasted effort.

It is noteworthy that nothing in these guidelines restricts small experiments to taking only small steps or to a slow discovery process. A behavior change process called adaptive muddling stresses this subtle but important issue and also adds the element of stability to the small experiment framework (De Young and Kaplan, 1988). A stability component is used to reduce the cost of failure for the individuals involved. It also makes highly improbable unchecked and disorienting social change. With a safety net in place people need not privilege the status quo by investigating only marginal behavior change. Far reaching change can be contemplated, explored and tentatively adopted. The scale of the experiment may be small but adaptive muddling supports people exploring life-changing responses to the advent of biophysical limits.

The small experiment notion also provides researchers with a framework for exploring a number of behavioral questions with important practical implications. Among the questions that seem to me most urgent to explore are the following: what are the conditions under which people domesticate the notion of a dramatic biophysical descent? Does the new behavioral context require a shift from green consumerism to green citizenship? Are there intrinsic reward embedded in crafting a response that may hasten the process? Might it be possible that crafting a response to energy descent directly increases well-being? Each is briefly outlined below in the hope that they inspire future work or, where sufficient research exists to fully address the question, package known science as guidelines to "give away" to practitioners. Clearly, this list is not exhaustive. Researchable questions about the behavioral aspects of energy descent abound and span all of the social sciences.

PRE-FAMILIARIZATION

In conversations about behavior, it is often claimed that people resist change because they rigidly anchor to the status quo. Also referred to as behavioral inertia, this tendency has been identified as a major impediment in efforts to get people and institutions to adapt to global environmental change (World Bank, 2009). The power of the current situation is related to cognitive availability (Tversky and Kahneman, 1973). The instances or examples that can most readily be thought of, those that are most mentally available, become powerful predictors of the things to which people attend and that motivate them. Thus, it would seem that the existing state of the world is what is both justified and deemed desirable (Jost et al., 2004). Under this framing, crafting a response to an energy descent would be heavily burdened by the collective, tangible and century-long experience of exponential growth in available energy, material consumption and consumer sovereignty.

However, an alternative perspective is to reframe what might appear to be a bias toward the status quo as, instead, a bias toward the familiar (Kaplan and Kaplan, 1983). Although this may sound as if it is an insignificant, perhaps even an academic distinction, it may be one with major implications for adapting to the coming downshift. A status quo bias means that very little can change, and what does change will stay close to present circumstances. A familiarity bias, in contrast, means that change is limited not by where people are now but is also affected by what they know and where they imagine themselves going.

Clearly, adapting to a long-drawn decline in resource availability is not something with which people are currently familiar. We can know that humans once lived this way, and that many still do, but most citizens of industrial society do not. The researchable question here is how such familiarity might be influenced. Does a bias for the familiar always lead people to favor the more physically tangible status quo rather than an imagined future reality, thus identifying this bias as a barrier for transitioning to a new behavior pattern? Or can tangible imagery create knowledge vivid enough to be a sufficient substitute for direct experience (De Young and Monroe, 1996; Kaplan, 1972; Hunt, 1984)? The challenge here is to discover if there are conditions under which knowledge of an emerging but not yet present energy descent, coupled with people's future aspirations, creates a familiarity as powerful as that created by people's current circumstances.

It might be fascinating to examine the role and successes of the arts and humanities in pre-familiarization. Kaplan (1972) points to the influence on the behavior of medieval society exerted by the anticipation of hell. Society needs far more useful examples than the existing melodramatic tales of techno-expansion (e.g., the Star Trek franchise) or eco-collapse (e.g., Hunger Games, The Road). Liftin (2011) has done this in her inspiring video narrative of the ecovillage movement. Similar efforts at affirmative storytelling exist at the Resilience[2] and Transition Network websites[3]. But missing, yet needed, are examples from a behavioral science perspective. The goal would be to share stories that not only honestly portray life under a prolonged and involuntary energy descent, but do so in a way that people crave the experience enough to seek it now.

[2]www.resilience.org

[3]www.transitionnetwork.org

GREEN CITIZENSHIP

Another way to understand the behavioral aspects of energy descent is to ask what social role people may need to play. Traditionally, in efforts to promote conservation behavior, people have been cast in the role of green consumer. The researchable question here is to ascertain if this role—once thought adequate for the creation of a sustainable society—is now insufficient to the task of responding to a long-drawn-out energy descent. Then, if the circumstances being imagined here demand that each of us take up green citizenship, how might this new role be promoted?

The distinction between these roles is subtle. Citizens likely have long-term intentions, motives and sources of social-support that differ from and are broader than those of consumers. These differences might constitute opportunities for behavior change. For instance, if the changing biophysical context can be conveyed in a way that does not frighten or overwhelm people, then we may be able to leverage considerable behavioral entrepreneurship.

But promoting green citizenship over green consumerism may require altered forms and formats of behavioral interventions. Yet, to date, almost all attention, funding, and science has been focused on the green consumer. The few exceptions suggest that green citizenship is a far more complex role than just selecting from among the green products in the marketplace (Gilg et al., 2005; Evans and Abrahamse, 2009). The related concept of ecological citizenship is also being explored (Dobson, 2003, 2006, 2007; Wolf et al., 2009; Wolf, 2011). It provides a starting point for answering the question posed here but it may need to be expanded to both fit the changing biophysical context and accommodate the broader array of motives that promote green citizenship. Of particular importance may be adding the requirement of coping with energy descent while having diminishing amounts of the infrastructure and capital inherent in industrial civilization. Furthermore, ecological citizenship presupposes that a deep attitude change precedes any significant behavior change. However, the behavioral response to energy descent may be driven as much by necessity as by a prior change in attitude, although the latter may hasten developing a response.

EMBEDDED BENEFITS

It is possible to imagine three broadly framed categories of behavior necessary to thrive through a prolonged downshift. The first is a response to the unsustainability of hyper-specialization. Individuals and their communities will need to become adept at many new or newly relearned skills. Knowledge and abilities either long dismissed as outdated or consigned to the ranks of the working-class may once again be widely needed. Rather than being efficient in narrow domains, people may need to become proficient at many crafts, have broad practical knowledge, retain the capacity to mindfully plan and restrain their behavior, and be willing to continuously build and share these competencies.

People will also need to be resourceful in ways true to the original definition of that word. Society will come to value the ability to deal with a difficult situation while utilizing only those resources currently at its disposal. Equally respected will be practical knowledge of how to work with the natural world in the thriftiest of ways. This is frugality, an ability that will need to become widespread if a community is to prosper.

Finally, there will be a need for people to maintain their prosocial inclinations and develop those character strengths that make them welcome as community members. For some people this will mean the ability to take and hold a leadership role. For everyone it will mean remaining cooperative through lean times and exhibiting forbearance and genuine kindness while under stress. These are attributes that will help people and their community to flourish.

Pursuing these behaviors likely will make it easier to transition through an energy downshift. The behavioral simplification mentioned earlier may go a long way in motivating people to pursue these actions since at some future time, in order to thrive, people will realize that there is no other option. But to prevent a last-minute, hasty, crisis response to the changing biophysical context, it would be necessary to begin this transition before circumstances demand it of us. As Liftin (2012) suggests, society would be better off if it begins prefiguring viable alternative life patterns in the midst of current circumstances.

Putting aside the existential benefit of starting the transition sooner rather than later, the challenges here are significant. Currently, except for a small subset of the population in industrial societies, the behaviors being called for are not those toward which people typically strive. Furthermore, the more common set of motives guiding the behavior of citizens of western society seem unlikely to initiate or sustain the behavior change that eventually will be needed. So, for instance, the need for frugality just mentioned may be valued in the abstract by people and eventually be necessary for community survival, yet it is presently practiced by very few individuals within industrial society. In fact, this once commonplace virtue (Nash, 1998) has become much maligned and dismissed as old-fashioned. It seems likely that any motivation to be frugal is presently overwhelmed by the motivation to be comfortable, to be successful or to better our family's standard-of-living. Thus the researchable question here is to determine if it is possible to motivate the needed behavior change in advance of any circumstances that demand it of us, and if that is possible, identify the procedures needed to do so.

The first part of the question, the possibility of initiating enduring behavior change, has been well explored. There is evidence that humans are capable of being intrinsically motivated to pursue the abilities mentioned above (Max-Neef, 1992; O'Brien and Wolf, 2010; Sheldon et al., 2011; Howell, 2013; Van der Werff et al., 2013). Chawla (1998) found that environmentally involved individuals credit intrinsic motivation when explaining their sense of integrity in living up to deep values and the competence they feel in both responding to difficulties and from interacting effectively with others. Crompton (2008) reports that, when compared to extrinsically motivated behavior, being intrinsically motivated leads to greater behavioral intensity and perseverance. Respondents in a study done by Wolf (2011) indicated that they derived substantial intrinsic satisfaction from pursuing behavior patterns that address environmental disruption and Brown and Kasser (2005) found that intrinsically oriented individuals engaged in a wider variety of conservation behaviors than did other respondents. In a series of small studies respondents from industrial societies reported deriving deep and direct intrinsic satisfactions from just the sort of behaviors that will be needed for a robust response to energy descent (De Young, 1996, 2000, 2012).

This brings us to the second part of the question—the need to develop and share procedures for using intrinsic motivation. What complicates the matter is that these motives can only be highlighted for people—they can be supported and leveraged but direct manipulation of an intrinsic motive is an oxymoron. The field of self-determination theory has pursued this issue for some decades (Deci and Ryan, 1985, 2012; Ryan and Deci, 2000) and has recently applied its findings to conservation behavior change (Osbaldiston and Sheldon, 2003; Sheldon et al., 2011). But a great deal more research is needed, particularly work that packages theoretical and empirical findings as guidelines for practitioners engaged in social transitions.

BIOPHYSICAL LIMITS, PSYCHOLOGICAL ABUNDANCE

A provocative suggestion is that a resource downshift has the potential to support, perhaps even to increase, well-being (Illich, 1974; Astyk, 2008). This notion might astonish members of industrial society where material deprivation is seen only as a source of suffering. The more common assumption about causality is in the opposite direction: interventions create conditions that enhance well-being which then allows people to build the personal resources needed to later act in sustainable and generative ways. For instance, Carter (2011) discusses how cultivating positive emotions, with the intention of thereby enhancing the personal resource categories of mindfulness, self-efficacy and positive relations with others, subsequently inspires environmentally responsible behaviors.

The researchable question here is whether it is possible that the effect also functions in the other direction, whereby enhanced well-being is derived from responding well to energy descent. There is some support emerging for this perspective: there are reports of positive interactions between the pursuit of sustainable behavior and the derived well-being elements of enhanced happiness and satisfaction (Corral-Verdugo et al., 2011a,b). Other researchers are exploring the interaction between the pursuit of conservation behavior and sustainable well-being (O'Brien, 2008; Kasser, 2009; Kjell, 2011). Brown and Kasser (2005) report that voluntarily reducing material consumption can be a direct source of subjective well-being (although it will be important to learn if this conservation-behavior-derived well-being also occurs under the involuntary reduction that biophysical limits may cause). Corral-Verdugo (2012) integrates these findings into a proposal for a positive psychology of sustainability where conservation behavior is viewed as the result of deliberation but is maintained by perseverance and derived satisfactions and where pursuing a sustainable life pattern enhances mental health.

However, environmental stewardship behavior may have different effects on two major categories of well-being (i.e., eudaimonia, or meaning-driven well-being versus hedonia, or pleasure-driven well-being). In particular, it is argued that there is a strong positive relationship between sustainability behavior and eudaimonic well-being (Myers, 2003; Jackson, 2005; Kasser, 2009). Venhoeven et al. (2013) report that pro-environmental behavior itself can be experienced as meaningful action that directly increases eudaimonic well-being, a suggestion that is consistent with the embedded benefits concept discussed above.

The possibility that pro-environmental behavior may increase eudaimonic well-being is made all the more significant by a recent discovery that pursuing different types of well-being has a differential effect on the human stress response and immune system functioning. Fredrickson et al. (2013) report that being in a state of hedonic well-being produces an undesirable elevation of inflammatory gene expression, while experiencing eudaimonic well-being causes a beneficial up-regulation of antibody synthesis genes and a down-regulation of pro-inflammatory genes. Thus, it sometimes may be ill advised to focus on the pleasant natural consequences of a behavior or to add pleasurable aspects to those behaviors lacking them. From the perspective of physiological stress and immune system functioning, the lack of inherent pleasure in the transition process may be far less important than people being able to frame the tasks involved as being consequential in some larger context. Thus, if handled well, the difficulty in responding to biophysical limits may, quite unexpectedly, be its redeeming quality.

Yet, in industrial society eudaimonic well-being is often trumped by the pursuit of hedonic pleasure. It is a researchable question whether the promise of eudaimonic well-being derived from responding well to a drawn-out energy descent can be made to overcome the hedonic pleasure gained from pursuing business-as-usual for as long as it lasts. This raises another confounding issue to be dealt with. Meaningful behavior can contribute to eudaimonic well-being, yet to have that effect it seems crucial that the choice to act be autonomously initiated (Ryan and Deci, 2000; Ryan et al., 2008; Venhoeven et al., 2013). External coercion or temptation of any sort or from any source to pursue a sustainable pattern-of-living might preclude any gain in eudaimonic well-being (Evans and Jackson, 2008) and thus negate any subsequent health benefits. As Venhoeven et al. (2013, p. 1379) point out, "it is more likely that only those who deliberately choose a pro-environmental lifestyle will gain eudaimonic well-being from their engagement."

This poses a dilemma since under an energy descent scenario the need to respond could hardly be thought of as autonomously chosen. If the ultimate goal is to encourage durable behavior change while also enhancing well-being and health then it would be counterproductive to force people to relearn lost skills, pre-familiarize themselves with simple living patterns or adopt conservation behaviors. The researchable question here is whether it is possible to support autonomous motivation under conditions of immutable biophysical limits, and how to craft interventions that create, but not coerce, pre-familiarization.

Yet, despite the need for more research, psychology does have advice to offer. It has been known for some time that effective functioning benefits from an environment responsive to one's attempts to function (Carr and Lynch, 1968). An environment is responsive when it allows people to experiment and to tentatively try out new ideas even under the pressure of time and resource constraints (i.e., limits-to-growth). An environment that is open and supportive provides a setting where people can more easily learn for themselves. In a responsive environment people can discover how the world functions and what sorts of plans and intentions fit the new biophysical circumstances. Knowing what is and what is not achievable helps to focus one's attention on those areas that have the greater effect. This brings the discussion back to small experiments which become all the more important when the biophysical and behavioral context has changed from what people are familiar with.

CONCLUSION

It may seem that much of human behavior is at odds with living within biophysical limits. We have clearly overestimated the capacity of the planet to provide for growth of all kinds, to secure material well-being and to absorb the waste of industrial society. It seems that few members of that society feel any sense of urgency in making these things right. Interventions to change this state of affairs have not had the needed effect. This assessment has brought pause to the environmental and conservation psychology community.

How we respond to the coming age of biophysical limits is one of the defining questions of our time. Yet, there are several reasons why this is a difficult topic to discuss. First, if the biophysical scenario happens anywhere near as outlined above, then modern civilization is facing major changes for which it is currently unprepared. Second, it is being suggested that the behavioral sciences have been ignoring the implications of this scenario. In fact, it may be difficult to take up the challenge of responding to ecological limits since taking that step could be construed as abandoning other cherished social goals, the pursuit of which might depend on the largess of industrial society. Of course, a reassessment of the changing biophysical context suggests that industrial society soon may be hard pressed to continue supporting our pursuit of those valued objectives, thus calling for a realignment of our approach. Finally, a tenet of environmental communication is to emphasize only the positive and to highlight success stories, to do otherwise is to risk losing the audience. However, if society is facing a challenge as daunting as that discussed here then it deserves to be told the effects of reaching biophysical limits and the costs of ignoring those limits.

Society still has options. There is a great deal that the behavioral sciences can do to ease the coming transition. The task, if we are willing to take it up, is to help people cope with the realization that everyday life may soon differ substantially from conventional expectations and to help them envision an alternative to their current relationship with resources. Acknowledging the biophysical trends is the sobering part. Next comes the hopeful part, indeed the exciting part.

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Climate change: time to Do Something Different

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There is now very little, if any, doubt that the global climate is changing and that this is in some way related to human behavior through unsustainable preferences in lifestyle and organizational practices. Despite the near conclusive evidence of the positive relationship between greenhouse gas emissions and global warming, a small proportion of people remain unconvinced. More importantly, even among the much larger number of people who accept a link between human behavior and climate change, many are inactive, or insufficiently active, in attempting to remedy the situation. We suggest this is partly because people are unaware both of how their day-to-day behaviors connect with energy consumption and carbon emissions, and of the behavioral alternatives that are available to them. This, we believe, is a key reason why individual lifestyles and organizational practices continue in an unsustainable way. We also suggest that the psychologists and behavioral researchers who seek to develop a better understanding of people's relationship with, and reaction to, environmental issues, might also be on track to suffer a similar blindness. They risk becoming fixed on investigating a limited range of established variables, perhaps to the detriment of alternative approaches that are more practically oriented though, so far, less well explored empirically. In this article, we present the Framework for Internal Transformation as an alternative perspective on the variables that might underpin pro-environmental activity and behavior change. After briefly reviewing the related literature, we outline that framework. Then we present some early empirical data to show its relationship to a range of pro-environmental indices. We follow with a discussion of the framework's relevance in relation to pro-environmental behavior change and make proposals for future research.

Keywords: climate change, pro-environmental behavior, behavioral flexibility, habit, awareness

INTRODUCTION

There is now very little, if any, doubt regarding the connection between human behavior, carbon emissions, and changes to the world's climate. The scientific evidence surrounding climate change has grown considerably over the past three decades following the UN Conference on the Changing Atmosphere in 1988. More recently, a report compiled by an international consortium of scientists, the largest of its kind to date, has suggested that the large majority of climate researchers agree that human activity is contributing to global warming (Doran and Zimmerman, 2009; IPCC, 2013). To quote, the UN's climate-panel scientists are 95% certain that humans are the "dominant cause" of global warming since the 1950s. Cumulatively, there is a clear message emanating from the scientific evidence: there is a significant relationship between changes to the climate and human behavior, as reflected in lifestyle preferences and organizational practices.

Despite the increasing scientific evidence it seems that a large majority of people still remain either unaware, in denial, or otherwise disengaged with the problem of climate change. This is reflected in the fact that UK energy consumption relating to transportation and households has continued to rise in recent years (DEFRA, 2006; notwithstanding some small drops recently, largely as a result of the financial recession). The IPCC (2013) suggests that human behavior is responsible for more than half of the observed increases in the climate. Elsewhere, it is also reported that only a minority of people are taking action to mitigate the effect (Whitmarsh, 2009). This means that for most individuals, daily life continues in a way that is unsustainable.

There are a variety of broadly psychological questions – that is, questions relating to human cognition, affect, and behavior – that arise in relation to climate change and sustainability. Do people have a realistic awareness of the scientific evidence showing the connection between human behavior in general and changes to the earth's climate? If so, how does this make them feel and act? How aware are people of the effects of their own personal behavior and how this behavior might itself be unsustainable? In this regard, how aware are people of the alternative behavioral options that are available to them? And how willing and capable are people of changing their behavior in the cause of improved sustainability (explicitly acknowledging here the distinct difference between willingness and capability)? It is clear that these questions, and the answers to them, present a set of interrelated challenges to researchers who seek to better understand the relationship between people and their changing environment.

In this paper, we are not primarily interested in exploring pro-environmental behavior change in those who, notwithstanding the scientific near-consensus, are either skeptical or outright hostile to any posited link between human activity and climate change. According to figures from various sources (Spence et al., 2010; YouGov, 2013), around 5% of UK adults do not believe that climate change is a real phenomenon at all, with a further 20% or so believing that, while climate change is real, it is primarily caused by natural processes other than human activity. Lewandowsky et al. (2013a,b) have investigated members of this skeptical minority in relation, for instance, to their political views and to their concomitant rejection of other scientific consensuses (see also, Specter, 2009). The conclusions of Lewandowsky et al. (2013a,b) lead us to think it unlikely that a significant proportion of this minority will be susceptible any time soon to pro-environmental psychological interventions. (Indeed, any attempt along these lines is likely to be regarded as sinister and, if anything, to have the opposite of its intended effect.) For this reason, this paper focusses on how psychological interventions might assist the majority of people who accept anthropogenic climate change, and the closely related majority (55–60%, according to Thornton, 2009; Spence et al., 2010, respectively) who would like to do more to help the environment. Given the figures, we believe that any public policy would do well to have the same focus.

Among the majority who accept the existence of climate change and its relationship with human behavior, we suggest that one of the primary challenges for practical pro-environmental behavior change is a lack of attention and/or awareness, with this lack evident at two related levels. Dealing with attention first, people are very often sufficiently focused on activities related to their core proximal goals that they pay little or no attention to the environmental consequences of those activities, these being of secondary concern at best. For example, drawing on the second author's experience of advising small companies on ways to cut their carbon emissions, the first challenge was often temporarily to draw attention away from the core business goal (i.e., generating products for market) and toward non-core aspects of a given business (such as the energy used for lighting and heating), aspects which nonetheless had a substantial effect on costs as well as environmental credentials. Without clients' attention being so diverted, even temporarily, it was difficult even to begin a conversation about pro-environmental behavior. We have referred previously (Page and Page, 2011) to this fundamental attentional problem as being somewhat akin to what is called, in the perceptual and cognitive domain, 'inattentional blindness.' The mapping is not perfect, however, as wasted energy, say, is not literally present in the visual field. What is important though is to establish environmental concerns in the "attentional set" of the target audience for behavior change. Naturally, in circumstances where the consequences to an individual or organization of, for example, wasted energy are dramatic - such as when the cost of energy is extremely high – then there is an increased chance that attention is drawn to the otherwise unattended problem, in as much as the core goal (e.g., profit making) is directly affected. At present, it does not seem that increased carbon emissions are associated with sufficiently negative consequences to make them a sufficiently salient dimension of everyday activities. For example, for the richest decile of UK residents, the decile for whom personal carbon emissions are the highest, energy costs make up only 3.5% of their domestic expenditure, a percentage clearly insufficient to draw attention and to promote action (Vaze, 2009).

Second, regarding awareness, even once attention has been drawn toward issues of environmental concern, there is very often a lack of awareness/knowledge regarding the measures that could plausibly be taken to ameliorate the position. Taking again the example of a small business, one's attention might be drawn to the high cost of lighting, but without both an awareness of potential alternatives and knowledge relating to the cost- and energy-saving consequences of each, significant behavior change is unlikely to occur. In previous work (Page and Page, 2011), we referred to this process of drawing attention to unattended problems and proposing viable solutions as the opportunities component of what we called the HOT topics of pro-environmental behavior change (Habits Opportunities Thoughts).

For people who are, in principle, open to change, another important aspect to consider is their personal belief that they are even capable of changing their behavior – an individual's level of self-efficacy (Bandura, 1994). This is important, as the extent to which they believe that their specific efforts will be successful helps determine people's behavioral motivation. Without sufficient self-efficacy, people might avoid attempting a specific behavioral change because they do not believe they are capable of its successful implementation. For this reason, we, among others (see below) suggest that a second key step in any intervention seeking to encourage pro-environmental behavior change involves developing intrinsic beliefs relating to self-efficacy so that people feel confident and empowered to take a different course of action.

It is not only "other people" who need to be attentive to alternative courses of action. Those psychologists and behavioral researchers who seek to develop a better understanding of pro-environmental behavior (and we include ourselves in this designation) might also need to broaden their attentional set. Based on a review of the literature on models of pro-environmental behavior and frameworks for pro-environmental behavior change (summarized below and reported in more detail elsewhere; see Page, in preparation), we suggest that a large majority of the theoretical and empirical research on pro-environmental behavior has become rather fixated on investigating, further investigating, and micro-refining a somewhat limited range of established variables, perhaps to the detriment of alternative approaches. Environmental researchers are, it seems, liable to become inattentive to novel approaches to behavior change in general, and to pro-environmental behavior change in particular.

With this in mind, we present below a preliminary investigation of a relatively novel framework for behavior change – called the Framework for Internal Transformation (FIT; Fletcher and Stead, 2000) – as it relates to pro-environmental action. In so doing, we organize the paper in the following way. First, we start by outlining some of the popular and empirically established frameworks relating to pro-environmental behavior that have placed emphasis on affective, cognitive, and behavioral dimensions. We consider the relative success that these psychological and behavioral approaches have enjoyed in the past. We then suggest that the net be cast rather wider in the search for psychological techniques that might usefully be applied in this domain and present the FIT Framework as a possible alternative approach that might have relevance in this domain. We then consider the applicability of FIT to pro-environmental behavior and present some preliminary empirical data. Based on the empirical insights offered by this early research, we consider the relevance of a FIT-based intervention for pro-environmental behavior change more generally.

REVIEW OF PSYCHOLOGICAL APPROACHES TO PRO-ENVIRONMENTAL BEHAVIOR CHANGE

There are multiple and distinct types of pro-environmental behavior that have been considered from a variety of theoretical perspectives. These include environmental activism; non-activist public behaviors such as environmental citizenship or support and acceptance of public policies; private environmental activism; and environmental behavior in organizations (Stern, 2000). Several psychological theories and behavioral models have been designed specifically to explain the different types of pro-environmental behavior and efforts at pro-environmental behavior change [e.g., the Value-Belief-Norm Theory (VBN), Stern, 2000]. There are also other models of behavior that are more generic in nature and were first designed to explain behavior of other types, before being applied to pro-environmental activity [e.g., the Theory of Planned Behavior (TPB), Ajzen, 1991].

Regardless of their origin, the models each place a different emphasis on the factors that might influence pro-environmental behavior. Overall, they have often reflected two main types. The first type places greater emphasis on individual agency and the individual as the locus of behavior. From this perspective, behavior is perceived as an outcome of competing influences that are decided upon by the individual, typically in a balanced and rational way. Accordingly, behavior is largely determined by the strength of influence of an individual's personal affective, cognitive, and/or behavioral characteristics and (perceived) competencies. In contrast, the second type of model is focused more on the social and physical context in which the behavior might occur. Approaches of this type place greater emphasis on the role of contextual and extrinsic factors that are, to a greater extent, perceived to be outside of individual control [e.g., Social Practice Theory (SPT), Hargreaves, 2011]. There are, of course, theories and models that sit astride these two camps and emphasize the interplay of both individual characteristics and contextual forces (e.g., the Comprehensive Action Determination Model; Klöckner and Blöbaum, 2010). However, despite such interactions being acknowledged in the theoretical frameworks that seek to explain pro-environmental behavior, we would argue that the significance of these interactions has often been underplayed in the models that seek to support pro-environmental behavior *change*.

Two popular psychological models of pro-environmental behavior that place greater emphasis on the role of individual characteristics are the Norm Activation Theory (NAT; Schwartz, 1977) and the VBN (Stern, 2000). The former was originally designed to explain altruistic and helping behaviors but in recent years it has been applied more widely to pro-environmental behaviors; this followed the conceptualization of such behaviors as moral acts that are determined by a sense of what it is right or wrong to do (Thøgersen, 1996). In contrast, the VBN approach was designed specifically to explain pro-environmental behaviors. In terms of their similarities, both the NAT and the VBN emphasize the influence of affect, values and beliefs in determining pro-environmental behavior.

According to the NAT, pro-environmental behavior occurs when people feel morally obliged to act in a given situation, based on the activation of a personal norm. The triggers to norm activation include: an awareness of the need for help; an awareness of the consequences of behavior; felt ascription of responsibility; and sufficient perceived behavior control to perform the action. Consistent with our previous characterization, the first two of these variables are dependent on an individual's cognitive awareness not only of the need to act but also of the consequences of various actions. The third variable describes the strength of the affective relationship or a personal motivation to act, while the fourth can be described as an individual's perception of their ability to act, as reflected in their perceived level of self-efficacy (Schwartz, 1977).

For the VBN, the strength of personal biospheric, altruistic, and egoistic beliefs underpins pro-environmental behavior. The VBN theory is a more inclusive framework than the NAT, as it identifies the attitudinal factors and personal capabilities of individuals, as well as the influence of contextual forces and habits. According to VBN, the causal chain starts with the strength of an individual's core beliefs, values and norms, which determine an individual's overall predisposition to act with pro-environmental intent. Three different types of value are identified: biospheric – a strong connection to the natural world; altruistic – a strong connection to other people; and egoistic – a strong connection to self. The strength of biospheric beliefs influences personal considerations with respect to the interconnectedness between human activity and the biosphere (cf. the New Ecological Paradigm; Dunlap et al., 2000). These might, in turn, lead to a personal motivation to avoid adverse environmental consequences, as is evident in the willing majority described above. However, in order to take action, an individual must feel that they are capable of worthwhile action, even though this perception might be at odds with their actual behavioral capabilities. Again, though, it is acknowledged that an individual's attentional set and their personal level of self-efficacy are important in moving an individual from affect to action.

In addition to personal beliefs, the influence of habit is also acknowledged in the VBN theory (Stern, 2000). Habits are likely to have a significant impact on the degree to which people are aware and are capable of taking action. Research has shown that when behaviors become characteristic of habit, they are directed less by conscious awareness and intentions and more directed by cues in the context (Triandis, 1977; Ouellette and Wood, 1998; Bargh and Chartrand, 1999). Several pro-environmental behaviors have also been reported as having habit characteristics. For example, Danner et al. (2008) found that people who cycle regularly had highly accessible representations of cycling that were independent of their intentions to cycle. As such, behavior was performed somewhat automatically and relatively independently from cognitions. As well as influencing behavior directly, habits can also suppress the consideration of alternative behavioral options. For example, in an earlier study, Danner et al. (2007) found that the mental accessibility of habits increases with repetition and goes hand-in-hand with an inhibition of competing alternatives. In essence, when behavior becomes guided by habit, the behavior itself can happen automatically rather than intentionally, with alternatives barely considered.

The considerable amount of empirical research that has explored pro-environmental behavior and behavior change from the perspectives of the NAT and VBN theories has suggested that these models are more limited in explaining repetitive pro-environmental behaviors such as travel mode choice and recycling behaviors (see Stern, 2000; Hunecke et al., 2001; Harland et al., 2007). It appears, again, that pro-environmental behaviors can be guided more by habit rather than intention, perhaps helping to account for the value-action gap that is often reported in pro-environmental behavior research (Blake, 1999).

The role of habit in determining behavior has also been largely overlooked in models of behavior that emphasize the influence of cognitions. The TPB (Ajzen, 1991) is one of the most popular cognitive models of behavior. It was first developed to explain personal health behavior but has more recently been developed and applied to the domain of pro-environmental activity (see Donald et al., 2014). The model specifies three antecedent determinants of behavior, which have an indirect effect on behavior through their influence on behavior intention. The determinants are: attitudes toward the behavior, which reflect beliefs about the behavior and an evaluation of its expected outcomes; subjective norms, which reflect beliefs about the perceived social pressure to perform or not perform the behavior and an individual's motivation to comply; and perceived behavioral control, which reflects beliefs about one's capability and control to perform the behavior. The model suggests that favorable attitudes and subjective norms, coupled with perceptions of behavioral control, lead to strong behavioral intentions and, in turn, behavior.

The TPB model has been successfully applied to a range of different pro-environmental behavior intentions for both direct behaviors such as recycling (Cheung et al., 1999) and transport mode use (Donald et al., 2014), and indirect behaviors such as environmental activism (Fielding et al., 2008) and, more specifically, opposition to wind farm development (Read et al., 2013). It has also been successfully applied to pro-environmental behavior intentions in the workplace (Fielding et al., 2005; Greaves et al., 2013) though, overall, organizational settings have warranted far less empirical research and might pose different challenges for pro-environmental behavior compared with those encountered in a home context. In essence, the TPB is well supported in the pro-environmental domain. It has received and continues to receive, extensive empirical support.

The TPB is, however, not wholly without limitations. One problem concerns the ability of the model to predict actual behavior rather than behavioral intention. In line with the original model specification, much of the empirical research to date has explored the predictive value of the TPB toward behavioral intention rather than to behavior itself. The two are not the same. The predictive value of the TPB is substantially weaker for behavior compared to behavioral intention. In a meta-analytic review, Armitage and Conner (2001) found a 12% difference, from 27 to 39%, in explained variance between behavior and behavioral intention. As intimated above, the presence of habits is one factor that might account for this disparity. People do not do what they intend to do simply because the strength of habit relating to existing behaviors cannot be overcome by intentions alone. As with the value-action gap, habits might go some way to accounting for the intention-action gap that is also regularly reported in pro-environmental behavior research (Klöckner and Blöbaum, 2010).

Aside from the potential intervention of habit between intention and action, another limitation of TPB toward pro-environmental behavior research is the absence of a truly practical method for supporting people to *change* their behavior. TPB is a more useful model for understanding the variables that determine behavior than it is a framework for supporting pro-environmental behavior change. Two models that offer greater opportunities for better understanding and encouraging people's susceptibility or resistance to changing behavior are the Stages of Change (SoC) model (Prochaska et al., 1992) and the more recent stage model of self-regulated behavior change (SSBC; Bamberg, 2013).

The original SoC model defines behavior as being positioned at one of five stages that are temporarily ordered and qualitatively different. These reflect an individual's 'level of motivational readiness' (Heimlich and Ardoin, 2008, p. 279). The five stages are: (1) *pre-contemplation* – the individual is unaware of the problem and has no intention to change behavior; (2) *contemplation* – the individual is aware of the problem and is seriously considering changing behavior; (3) *preparation* – the individual is ready to change and is intending to take action; (4) *action* – the individual takes action to modify their behavior; and (5) *maintenance* – following action, the individual works to avoid relapse. Accordingly, a different intervention type is suggested for each stage, as each stage is likely to present a different challenge and hence to need a different approach (Nisbet and Gick, 2008). It is suggested that movement between stages is driven by two factors: an individual's level of self-efficacy and their decisional balance, the latter reflecting the outcome of individual assessment of the pros and cons of particular behaviors (Armitage et al., 2004). It is possible to move backward and forward through the stages.

In a similar way, the SSBC model (Bamberg, 2013), which was designed specifically for pro-environmental behavior change, defines four distinct qualitative stages through which behavior change occurs. The first three of these stages are based on a foundation of cognitive awareness and intention. They are defined as: (1) *pre-decisional* – individuals consider competing wishes and turn some of these into binding goals to form a goal intention. Upon development of a goal intention the individual transits to the second stage, (2) *pre-actional*, whereby a specific behavior intention for guiding action is deliberated and decided upon. Next, formation of the behavior intention moves the individual to the third stage (3) *actional* and a narrowing down of behavioral options to a specific behavior, which is formulated through an implementation intention. Lastly, commitment to an implementation intention moves the individual to the (4) *post-actional* stage whereby the new behavior is performed (Bamberg, 2011, 2013).

Both the SSCB (Bamberg, 2013) and the SoC models (Prochaska et al., 1992) offer promising approaches to leveraging change in relation to pro-environmental behavior. A recent application of the SSCB model to a social marketing campaign showed greater effectiveness for encouraging car use reduction in comparison to a standardized information package (Bamberg, 2013). Both models acknowledge and consider the blindness (in our terms) that people might have toward the target problem and in relation to their current behaviors. In the SSCB model in particular, this is challenged directly by getting people to commit to a goal intention. We see this as a significant advantage over the other models of behavior that we have described so far. The SoC model also explicitly acknowledges the importance of self-efficacy for supporting people to move through the different stages.

Although both the SoC and SSBC models offer promising insights into the encouraging of pro-environmental behavior change, others (see Morris et al., 2012) have suggested that they might be too egoistical in their approach, in as much as the models miss or underplay the influence of structural economic, environmental, and social factors that could also influence performance of pro-environmental behaviors. An alternative approach offered by the SPT (see Shove, 2010; Hargreaves, 2011) places greater emphasis on extrinsic factors and how these might influence pro-environmental behavior and behavior change. In particular, the SPT theory considers how behaviors are embedded in the structures of everyday life, in the routine performances of social practices such as cooking, driving, washing, and shopping. From this perspective, behaviors, whether they are pro- or anti-environmental, become embedded within social practices (Warde, 2005) and, in turn, are perceived by people as being "normal ways of life" (Shove, 2004, p. 117). Through the exposure and repetition of social practices in day-to-day life, behavioral sets develop and become associated with different practices. Subsequently, behaviors are no longer determined by an individual's personal competencies and intentions (as per NAM, VBN, TPB), but individuals become, instead, 'carriers' of social practices and thus become 'performers' of the behaviors that are required by the practice (Reckwitz, 2002). In essence, people develop behavioral habits and routines that are congruent with their environmental circumstances. As a consequence, people's awareness of their actions might be lowered, a factor that we identified above as a key barrier to behavior change. The structure that embedded social practices offer might, of course, be advantageous once pro-environmental behaviors are established. In essence, the relatively stable routinization of daily life enables people to perform pro-environmental behaviors somewhat automatically, without overexertion of conscious decision-making processes.

Empirical research has supported this characterization. Transport choice is perhaps the best researched of the areas in which automatic action is cited as a negative environmental factor; specifically, the near automatic favoring of the private car over public-transport alternatives is frequently attributed to the force of habit (e.g., Dahlstrand and Biel, 1997; Verplanken et al., 1997, 2008; Klöckner and Matthies, 2004; Davidov, 2007). One can imagine, too, that the unnecessary turning on (and leaving on) of lights or of heating systems, the disposal (rather than recycling) of waste, or the unnecessary use of water, would all be under the influence of habits, rather than being driven by the more rational consideration proposed in the NAT (Schwartz, 1977), VBN (Stern, 2000), and TPB (Ajzen, 1991) theories. Again, habits are not necessarily environmentally deleterious: one might equally well be in the habit of cycling to work, turning lights off and dutifully recycling. Nonetheless, the environmental problems with which we are currently faced suggest that these 'good' habits are not yet the norm and that environmentally deleterious habits pervade.

HABITUAL THINKING

So far in this article we have identified attention/awareness, self-efficacy, and behavioral habits as important considerations in the field of pro-environmental activity. We have suggested that both individuals and researchers might be prone to inattentional and habitual action, and that this might suppress their abilities to engage effectively with the problems that climate change presents. Up to now our attention on habit has been focused on behavior: we have considered how behavioral habits might support or impede pro-environmental activity in day-to-day life and have considered how habits might separate action from values, affect, and cognition. Next we briefly consider the process of habit development and how this might impede or support pro-environmental activity. In so doing, we further consider the connection between cognition, affect and behavior, and describe how cognitions and affect can themselves be habitual in character.

As well as their influence on behaviors, habits can also manifest in the way people think and feel. For example, in relation to the purchase of environmentally friendly detergents, Dahlstrand and Biel (1997) identified seven key steps in the development of an environmentally benign habit. These were: (1) activation (i.e., attending to the environment as a value); (2) attending to present behavior; (3) consideration of alternative behaviors; (4) planning new behavior; (5) testing new behavior; (6) evaluation of new behavior; and (7) establishment of new habit. Alongside each of these steps, they postulated factors that could either impede or promote progress at that point. It is notable that the first of Dahlstrand and Biel's (1997) seven steps comes under the general heading of attentiveness and supports the notion that many people simply do not attend to, and are hence not aware of, their behavior. This lack of awareness could certainly impede attempts to change behavior, particularly as people under its influence might never progress to the latter stages of the new-habit-forming process. For the third step (the consideration of alternative behaviors), Dahlstrand and Biel (1997) also identified 'negative beliefs about alternatives' as an impeding factor, while the presence of 'evident, existing alternatives' was considered a promoting factor at this level. In this model, therefore, beliefs potentially constrain both the range of alternative behaviors that are considered and the way in which those alternatives are conceived.

In a previous discussion of the role of beliefs in behavior change (Page and Page, 2011), we drew a parallel with the role that beliefs are considered to play in therapeutic settings informed by Cognitive Behavioral Therapy (CBT) theory. CBT theory is influenced by the Greek philosopher Epictetus, who famously wrote that, "Men [sic] are not disturbed by things, but by the view that they take of them." In the CBT conception, it is not events in the world that directly cause emotional or other disturbance. It is, instead, the thoughts/beliefs that an individual has about those events that intervene between events and feelings, and play a causal role in affecting the latter. In relation to automatic beliefs in pro-environmental behavior change, there is, we suggest, an analogous situation: the activation of just one negative environmental thought is enough to block entirely a change in behavior, even if that thought represents a cognitively distorted perspective on the world. For this reason, we suggest that close attention to thoughts, and in particular those negative thoughts that leap automatically to mind, is likely to be a necessary component of successful pro-environmental intervention.

We have highlighted the influence of cognitive, affective, and behavioral habits on pro-environmental behavior and behavior change. We propose that researchers need to take more serious consideration of the constraints that habits and behavioral inflexibility place on human action and the possibilities of change, this to include a willingness on the part of the researchers themselves (ourselves) to exhibit more flexibility in their (our) own investigations. In the spirit of this recommendation, therefore, in what follows we consider the FIT framework (Fletcher and Stead, 2000) as an alternative model of behavior that is explicitly accompanied by an associated framework of behavior change. By way of contrast with the models described above, FIT is a model that does, to a certain extent, consider the potential impact of cognitive and behavioral habits on pro-environmental behavior and behavior-change efforts, by explicitly measuring behavioral flexibility. The FIT framework has not been tried and tested in relation to pro-environmental activity, in the way that many of the preceding approaches have been. Nonetheless, we are currently undertaking empirical work to assess its value in this field. There follows a description of the FIT behavioral framework and our first empirical evaluation of its relationship with pro-environmental behavior.

THE FIT FRAMEWORK

The FIT framework (Fletcher and Stead, 2000) comprises a collection of psychometrically validated tools (principally, the FIT Profiler; Fletcher, 1999) and a variety of behavioral interventions (principally, a Do Something Different programme). At its inception FIT, which is an acronym for Framework for Internal Transformation, was proposed as a framework to understand personal effectiveness in decision-making and behavior. It was offered as a theoretical framework for understanding the differences between people in how they cope with the situations they encounter (Fletcher and Stead, 2000). In line with this, much of the early research on FIT was focused on personal strain levels (e.g., see Fletcher, 1991). FIT is formulated around a framework of cognitive and behavioral competencies and strengths that, it is suggested, guide an individual's perceptions of different situations and the demands that associate with these. In particular, the framework focuses on five cognitive competencies; also named Constancies, and the degree of flexibility across 15 behavioral dimensions, termed behavioral flexibility. These dimensions are perceived significantly to influence an individual's decision-making processes and their execution of behavioral choices.

Framework for Internal Transformation theory acknowledges that behavior and thinking-style can both be prone to inflexibility and habit. Unlike other models of behavior, FIT emphasizes the idea that for maximum effectiveness one would not want to be located at any given point along a particular behavioral dimension. Instead, it is suggested that individuals should be comfortable operating at widely dispersed points along the dimension, so as to display the flexibility that is required to cope effectively and efficiently in different circumstances. To give an example, using a dimension of Introversion–Extroversion: FIT theory emphasizes that rather than seeking to locate one's "character" at a particular point along this dimension, the varying demands of the real world would recommend flexibility, that is, sometimes being introverted, sometimes extroverted, as the occasion requires. The enhancement of such flexibility is intended, therefore, to counteract habitual, unaware behavior.

The FIT Profiler (Fletcher, 1999) measures the 15 behavioral dimensions defined by the FIT framework, and specifically measures the degree of flexibility in each (see **Table 1**). It also measures the five cognitive Constancies (Awareness, Balance, Conscience, Fearlessness, Self-Responsibility; see **Table 2**), in acknowledgment that thinking-style too can be prone to inflexibility and habit. The behavioral dimensions are defined by Fletcher and

Table 1 | Dimensions of Behavioral Flexibility measured by the FIT Profiler.

Pole 1		Pole 2	Pole 1		Pole 2
Assertive	V	Unassertive	Behave as I wish	V	Behave as others expect
Conventional	V	Unconventional	Systematic	V	Spontaneous
Cautious	V	Trusting	Open-minded	V	Single-minded
Predictable	V	Unpredictable	Extroverted	V	Introverted
Energetic/Driven	V	Calm/relaxed	Definite	V	Flexible
Reactive	V	Proactive	Lively	V	Not lively
Group orientated	V	Individually orientated	Gentle	V	Firm
Risk taker	V	Cautious			

Table 2 | Cognitive Constancies measured by the FIT Profiler.

Constancy	Item
Awareness	Are you always clear as to why you did something or are you often surprised?
Balance	When at work is your mind on other things?
Conscience	Do you believe you have to tell lies to succeed?
Fearlessness	Do fearful feelings stop you from doing things you want to do?
Self-Responsibility	Do you feel in control?

Stead (2000) as providing the 'blueprint' that allows individuals to behave effectively and flexibly across different situations. The behaviors are not considered as fixed traits but as competencies that are trainable and can be developed. The FIT Profiler measures such behavioral flexibility and directs its development.

Fletcher and Stead (2000, p. 22) suggest that most people will have a "comfort zone" on each behavioral dimension. It is likely that this will reflect personal preferences and the way in which someone typically behaves in a given situation; in other words, it reflects their habitual tendencies. FIT theory acknowledges that as well as identifying personal preferences in each of the cognitive and behavioral dimensions, it is also important to offer a framework to encourage behavior change and personal development. The purpose of the associated FIT-Do Something Different (DSD) intervention is to expand the size of personal 'comfort zones' so that these exceed the "discomfort zone" (Fletcher and Stead, 2000, p. 22). People might, therefore, be better equipped to behave appropriately and flexibly in accordance with circumstance, and as guided by their conscious cognitions (Constancies).

Fletcher and Stead (2000) describe the cognitive Constancies as underpinning action. Furthermore, they suggest that if the Constancies are aligned at similar levels, they are more likely to guide decision-making and behavior that is effective and accords with current circumstance and personalized goals, rather than simply being driven by force of habit. Like Behavioral Flexibility, the cognitive Constancies are described as trainable. They can be strengthened and developed. There are five Constancies (see **Table 2**) and it is plausible that each has a role to play in determining pro-environmental behavior and driving efforts toward pro-environmental behavior change.

Having high levels of Awareness, which by definition is the degree to which an individual monitors and attends to their external and internal world, can be thought of as an antidote to being a habit-machine. It is about being awake and monitoring internal and external states and using feedback to guide actions, thoughts, and feelings. In relation to pro-environmental behavior and change, we suggest that individuals who have a higher level of Awareness will also be more aware of issues relating to climate change, the degree of sustainability in their personal lifestyle, the impact of their current behaviors, and the possibilities of change to become more pro-environmental.

The Balance Constancy is described as the ability of people to ensure every aspect of life receives due care and attention so that each part, be it work, non-work or self, is in-sync and that no one dominates. Accordingly, a person who scores high on Balance is able to prioritize different aspects of their life and allocate cognitive and behavioral resources toward these in accordance with demand. In relation to sustainability, a person with a low level of Balance might compromise this aspect of their lifestyle, potentially resulting in aspects of pro-environmental activity being pushed aside and excluded in the cognitions or behaviors of daily life. In contrast, individuals with higher levels of Balance might consider issues relating to sustainability as a priority alongside others, with the consequence that pro-environmental behavior is more prominent in their daily life.

The third Constancy is Conscience. This is described as the moral compass for decision-making and behavior. Conscience allows people to differentiate right from wrong and act on doing the right thing. It might then follow that an individual with a high level of Conscience will endeavor to make every decision an ethically and morally correct one. Fletcher and Stead (2000) suggest that individuals who have a high level of Conscience will never compromise morals in order to achieve an external goal. By plausible extension, individuals with higher levels of Conscience might feel more connected with issues of sustainability and therefore become engaged, both cognitively and behaviorally, with pro-environmental activity.

The fourth Constancy identified in the FIT framework is Fearlessness. Negative emotions such as fear and anxiety have been identified as barriers to action in several models of health behavior (see, e.g., Beck, 1967). When fear is particularly high it can restrict many aspects of daily life and can skew rational thought and action; excessive levels of fear can cause phobias. Fear can often be the main driver of behavior and the decisions people make. The FIT framework conceives fear as the emotional limiter of behavior that keeps people within their comfort zones, doing the things they have always done. It acknowledges that the influence of fear on people's actions, choices and decisions might be unconscious, or, if felt, to be too powerful to overcome. As a consequence, FIT suggests that people stick to 'safe' patterns of behavior. In contrast, Fearlessness is achieved when people, to a significant degree, disconnect emotion from decision-making. Fearlessness supports individuals to act outside of their behavioral comfort zone, in accordance with their personal wants and desires. A sufficient level of Fearlessness might be necessary to encourage people to embed pro-environmental activities into their lifestyles, particularly if there are external barriers such as social norms that run counter to the desired actions. Higher levels of Fearlessness might give people the confidence to experiment with new and different ways of behaving, without the fear of failure.

The FIT framework (Fletcher and Stead, 2000) describes the Self-Responsibility Constancy as the barometer for measuring the extent to which an individual takes charge of their life and accepts responsibility for their actions and the things that happen to them, regardless of factors outside of their control. It is suggested that an individual who is self-responsible, will shape his or her own world. They will not believe in luck and chance, nor will they blame external factors for the things that happen to them. Accordingly, an individual who is self-responsible takes an active role in shaping their world so that it suits them. In relation to sustainability, it might be that an individual's level of Self-Responsibility will influence their felt level of personal responsibility to do something to reduce their environmental impact. Having a high level of Self-Responsibility might strengthen the level of personal responsibility that an individual feels toward climate change and their personal contributions to it. This, in turn, might help initiate pro-environmental action.

As described above, the strength of an individual's Constancies and their degree of Behavioral Flexibility might be separately important for determining the level of pro-environmental activity in personal lifestyles. In addition, the connectedness between both dimensions might also be an important consideration. The FIT Framework (Fletcher and Stead, 2000) emphasizes a bi-directional connection between people's cognitions and their behavior. It suggests that Constancies can guide effective and flexible decision-making behavior and, in return, the experiences that are encountered can, through behavioral feedback, help to develop the Constancies further. The strength of this bidirectional relationship, particularly the effect of actions on thoughts, has often been underplayed in other models of behavior and frameworks for behavior change.

As noted previously, the FIT framework suggests that the cognitive Constancies provide the foundation for action; they guide decision-making and behavior. As such, they can act as a direct or indirect target for behavior change interventions. A direct approach to change would seek to develop the strength of each Constancy in order to lever changes in behavior. This is the approach supported by most existing psychological models of behavior and frameworks for behavior change. However, as mentioned previously, this method does not always result in new patterns of behavior and can result in the thinking-action gap often seen (Klöckner and Blöbaum, 2010). An alternative approach would be to change cognitions indirectly by developing behavior. According to this perspective, which subsumes an action-oriented approach, behavior is targeted directly to leverage indirect changes in thinking. The behavior change approach supported by the FIT framework, historically called DSD, uses both an indirect and direct approach to support behavior change. We suggest that in as much as it simultaneously targets cognitions and behavior (i.e., behavior independent of cognitions), the FIT framework might be a useful alternative approach for pro-environmental behavior change.

The FIT framework and DSD approach are novel perspectives that have received limited empirical examination. The empirical work that has been undertaken has mainly focused on health-related outcomes such as stress, weight loss, and family functioning (see Fletcher et al., 2011; Sharma, 2011). As far as we are aware, this is the first empirical study to explore the relationship between FIT variables and pro-environmental activity. Therefore, before we describe in detail the behavior change framework associated with the FIT framework, we first need to establish if there any relationships between FIT variables and pro-environmental activity and, if so, what these might comprise. What follows, therefore, is a description of our first empirical research exploring the relationship between FIT variables and indices of pro-environmental activity.

Based on our preceding rationale, we expect positive relationships between each of the FIT Constancies and cognitive and behavioral measures of pro-environmental activity. We also expect a positive relationship between Behavioral Flexibility and pro-environmental activity. This is because individuals who are more behaviorally flexible are likely to be more capable of adapting to new challenges (such as climate change) and of developing behavioral responses to mitigate their impact.

MATERIALS AND METHODS

As this is the first empirical study that seeks to explore the relationships between FIT variables and pro-environmental activity, we thought it would be useful to identify the relationships in a sample that was as diverse as possible. With this intention in mind, we used an online survey to capture the relationships in a cross-section of participants that was obtained through a convenience sampling method. All respondents volunteered and gave informed consent to participate in the research. They were assured of the anonymity of the data they provided. The online survey was composed of several scales (as described below), and although they were not uncomplicated, responses suggested that respondents had understood the instructions. The survey was open for ∼2-months during which time 431 respondents started the questionnaire and 325 completed it in full. This equated to a 75% completion rate overall. Due to the possibility that the non-completing respondents later returned to the questionnaire and started to complete it a second time, data for the non-completers were removed. Therefore the results are based on a sample of 325 respondents.

RESPONDENTS

Respondents in the study were 325 individuals [$n = 87$ (27%) male; $n = 237$ (73%) female], ages ranged from 17 to 71 years ($M = 28.36$, $SD = 11.81$). Two hundred and twenty four (69%) respondents were of white-British origin; 58 (18%) were Asian; 12 (4%) were Black; 7 (2%) were Chinese; 7 (2%) were of mixed race; and 8 (4%) other ethnicities. Regarding job type, 157 (48%) respondents were studying or in education; 47 (3%) were in administrative/secretarial roles; 86 (26%) were in professional roles; 22 (7%) were in managerial roles; 7 (2%) were self-employed; and 5 (2%) were unemployed or not working. One person did not report their type of work. Regarding highest educational qualification, 6 (2%) respondents had a PhD; 37 (11%) had an MSc degree; 108 (33%) had a BSc degree; 162 (50%) had A-Levels; and 11 (4%) had GCSEs. One person reported no educational qualifications. Respondents were self-selecting volunteers to the research and formed an opportunity sample.

We have described in detail here the characteristics of the sample. This is to give an indication of the diversity that was present. These demographics were not used to make smaller group comparisons in the inferential analyses; this was not the intention of this exploratory research.

MATERIALS

The scales in the online survey measured dimensions of pro-environmental activity, personal FIT levels, and demographic information, as follows.

Indicators of sustainability

We used three separate scales to measure respondents' cognitive and behavioral engagement with pro-environmental activity. The three scales were systematically connected such that they each separately assessed respondents' pro-environmental thinking and behavior on a similar range of pro-environmental activities. We designed the survey in this way so that comparisons could be made between scores on the pro-environmental thinking and behavior scales, and between reported performance of pro-environmental behavior in different contexts.

The *pro-environmental thinking* scale measured cognitive aspects of sustainability across 37 items by asking respondents to rate the importance of a range of everyday pro-environmental behaviors for protecting the environment (e.g., "recycling materials") on a 7-point Likert scale from 1 (extremely unimportant) to 7 (extremely important). Higher scores on the scale (minimum = 37; maximum = 259) represented stronger cognitive engagement with pro-environmental activity, that is, respondents were aware and thought that a larger number of the behaviors were important for protecting the environment.

The *home pro-environmental behavior* scale measured how frequently respondents performed pro-environmental behaviors in a home context. The scale was composed of 27 items, all of which matched to the scale item on the pro-environmental thinking scale. The items were measured on a 6-point scale from 0 (never) to 5 (always). Higher scores on the scale (minimum = 0; maximum = 135) represented greater engagement with pro-environmental behaviors in a home context.

The *work pro-environmental behavior* scale measured how frequently respondents engaged in pro-environmental behaviors in a work context. The scale was composed of 24 items, which were, where possible, matched to items in the home pro-environmental behavior and pro-environmental thinking scales. The items were measured on a 6-point scale from 0 (never) to 5 (always). Higher scores on the scale (minimum = 0; maximum = 120) represented greater engagement with pro-environmental behaviors in a work context.

In consideration of the influence of habit on behavior, we thought it useful to include two scales to measure pro-environmental behavior separately in home and work contexts. This allowed us to explore whether there were any significant differences between pro-environmental activities at home and work.

The FIT Profiler

A short version of the FIT Profiler (Page and Fletcher, 2006) was used to measure personal levels of FITness. The shorter scale was chosen to reduce the overall length of the online survey and to align with the exploratory nature of the study. The full version of the FIT Profiler is 75 items and would have significantly added to the survey completion time. The items included in this shortened version were determined by a psychometric report produced by Page and Fletcher (2006). The scale was composed of 20 items, 15 items measured Behavioral Flexibility and five items were used as key indicators for each of the cognitive Constancies.

The *Behavioral Flexibility* scale measured the degree of flexibility in an individual's behavioral repertoire. The scale was composed of 15 bipolar items. Each item measured a different dimension of behavior as described by the FIT framework, e.g., "proactive vs. reactive," "extroverted vs. introverted" (see **Table 1**). To complete the scale, respondents were instructed to indicate their range of behavior (i.e., the size of their behavioral repertoire) on each item on an 11-point scale. The response scale for each item represents the two extremes of the behavior in question, with nine intermediate points. Respondents who are behaviorally flexible will indicate a large behavioral range across all of the scale items. This would be shown by a response that spans from one end of the scale to the other, encompassing all 11 points. In contrast, respondents who are less flexible will indicate a narrower response that is typically situated at one end of the scale. The size of the range is recorded for each item and this reflects an individual's degree of flexibility on the respective behavioral dimension. An overall Behavioral Flexibility score is computed as a percentage from the range scores of the 15 items (minimum = 0; maximum = 100); a higher score indicates a larger repertoire of behaviors, hence more Behavioral Flexibility.

The cognitive Constancies of Awareness, Balance, Conscience, Fearlessness, and Self-Responsibility were each measured by a single item. The item used for each was determined in a previous study that identified the psychometric properties of the FIT Profiler (Page and Fletcher, 2006). The strongest loading item for each Constancy scale was used in this shortened version of the scale. The Constancies were measured on a 0–10 scale with higher scores equating to higher levels of Awareness, Balance, Conscience, Fearlessness, and Self-Responsibility. A total score of the individual Constancy scores was computed to reflect the strength of FIT thinking. This is called FIT Integrity. Higher scores show higher levels of each Constancy (minimum = 0; maximum = 10) and overall FIT Integrity (minimum = 0; maximum = 100).

The psychometric report produced by Page and Fletcher (2006) identified the psychometric properties of the FIT Profiler in a sample of 1325. The results demonstrated good internal consistency for the cognitive Constancies: Cronbach's alpha values ranged from lowest 0.67 (Self-Responsibility) to highest 0.87 (Fearlessness); FIT Integrity = 0.87; and Behavioral Flexibility = 0.91. The test-re-test coefficients ranged from 0.40 for Balance to 0.89 for Overall FIT (a combined score of FIT Integrity and Behavioral Flexibility).

Biographical and lifestyle questions

Respondents indicated their age; gender; ethnicity; highest education qualification; work/education status; and work/education hours. This information was collected as background data to inform the characteristics of the sample. It was not used to make smaller group comparisons in the inferential analyses; this was not the intention of this pilot research.

DATA PREPARATION

Before proceeding with the data analysis we first acknowledge the self-report nature of the data and the possible implications of this. A self-reported survey approach was selected for ease of capturing a diverse sample for this pilot research. However, as with any self-reported data collection method, there is the potential that respondents might bias their responses toward social desirability. The distortion might be more prevalent here because the survey focuses on pro-environmental activity, a topic that has been shown to be prone toward the influence of social desirability (Schwarz, 1999).

The second limitation of using a self-report approach is that the answers provided do not necessarily reflect reality. In other words, the responses that respondents provide, particularly in relation to behavior, might not be representative of how they actually behave (see Huffman et al., 2014). This might be because respondents are intentionally distorting their answers for social desirability or because, as our reasoning throughout the paper has suggested, people are simply unaware of some aspects of the way they behave.

To mitigate these effects where possible, our analyses explored the relationships amongst the scale variables using within-subjects correlation analyses. In addition, the pro-environmental thinking and behavior scales, which contained a different number of items, were transformed to percentage scales prior to data analysis. The results for each scale are presented on a 0–100 scale with lower scores indicating lower levels of the variable measured.

RESULTS

DESCRIPTIVE STATISTICS AND RELIABILITIES

Considering the exploratory nature of this research and the novelty of the scales used, the first step was to check the descriptive properties and reliabilities of the scales. **Table 3** presents the alpha coefficient, mean, standard deviation, skewness, kurtosis, and other descriptive statistics for the pro-environmental activity and FIT Profiler scales. Overall, the alpha coefficients for the pro-environmental activity scales were highly satisfactory, ranging from 0.86 to 0.95 ($M = 0.89$). These results indicate substantial internal consistency of the scales. The scales also had acceptable (i.e., <1.00) levels of skewness and kurtosis, suggesting no serious deviations from normality.

Scores on the pro-environmental thinking scale were moderate. This indicates that respondents believe that many of the activities are important for protecting the environment. The empirical scores distributed well across the theoretical scale (minimum = 0; maximum = 100). The home pro-environmental behavior scores showed that, on average, respondents performed some but not all of the pro-environmental activities. The mean was situated just above the halfway position on the scale. Overall, the empirical scores distributed well across the theoretical scale (minimum = 0; maximum = 100). The work pro-environmental behavior scores distributed to the upper- but not lower-end of the theoretical distribution (minimum = 0; maximum = 100). This suggests that all respondents performed at least some of the work pro-environmental activities.

For the FIT Profiler, it was only possible to calculate alpha coefficients for scales composed of more than two items. The alpha coefficients for these scales were, in the main satisfactory, ranging from 0.42 to 0.89 ($M = 0.75$). The alpha value for FIT Integrity was low, however. This may well be expected when investigating psychological constructs (see Burch et al., 2008; Zibarras et al., 2008), especially when they are measured using a limited number of items (Rust and Golombok, 1999). As this scale was a reduced version of the 50 item scale, and was composed of items measuring different aspects of cognition, a lower alpha coefficient was not unexpected and should not be considered too concerning, especially considering the diversity and limited number of items included in the scale. The data had an acceptable (i.e., <1.00) level of skewness and kurtosis suggesting no serious deviations from normality.

Table 3 | Descriptive statistics and reliabilities for the pro-environmental and FIT Profiler scales ($N = 325$).

Scale	α	M	SE	95% CI LL	95% CI UL	Mdn	Minimum	Maximum	SD	Skewness	Kurtosis
Thinking	0.95	69.10	0.71	67.71	70.49	68.00	5.00	100.00	12.73	–0.30	0.18
Home bvr	0.86	58.48	0.80	56.91	60.06	58.00	9.00	96.00	14.45	–0.11	–0.02
Work bvr	0.86	65.05	0.96	63.15	66.94	65.00	13.00	99.00	17.40	–0.37	–0.25
Integrity	0.42	56.19	0.82	54.56	57.82	56.00	16.00	98.00	14.92	0.01	–0.31
Awareness	–	6.18	0.14	5.90	6.47	7.00	0.00	10.00	2.57	–0.37	–1.07
Balance	–	4.30	0.15	4.01	4.59	4.00	0.00	10.00	2.65	0.26	–0.95
Conscience	–	6.89	0.18	6.53	7.25	8.00	0.00	10.00	3.30	–0.81	–0.73
Fearlessness	–	4.54	0.15	4.24	4.84	4.00	0.00	10.00	2.71	0.29	–0.90
S-Responsibility	–	6.09	0.12	5.85	6.33	6.00	0.00	10.00	2.17	–0.40	–0.56
B-Flex	0.89	19.92	0.80	18.37	21.48	17.67	1.00	69.00	14.23	0.86	0.47

Thinking, pro-environmental thinking; Home bvr, home pro-environmental behavior; Work bvr, work pro-environmental behavior; S-Responsibility, Self-Responsibility; B-Flex, Behavioral Flexibility.

The Behavioral Flexibility scores were low and situated toward the lower end of the theoretical distribution (minimum = 1; maximum = 100). The FIT Integrity scores were moderate and distributed evenly across the theoretical scale (minimum = 0; maximum = 100). The scores did not reach the upper- or lower-ends of the scale suggesting that no respondents had either very poor or very high levels of Integrity.

Respondents reported lower levels of Balance and Fearlessness compared to the other Constancies. The variability of the Constancies was similar, indicating that there were approximately equal variations for each. Overall, the Constancy scores distributed evenly across the theoretical scales (minimum = 0; maximum = 10).

The alpha coefficients and descriptive statistics did, in the main, confirm the data suitable for parametric inferential analyses.

INTERCORRELATIONS

Indicators of sustainability

The relationships between the pro-environmental scales (pro-environmental thinking, home pro-environmental behavior and work pro-environmental behavior,) were positive, moderate-to-strong, and significant (see **Table 4**). However, they were not too strong, which suggests a degree of independence among the scales. The relationship between pro-environmental thinking and pro-environmental behavior differed according to context. A larger proportion of variance was explained by the correlation between pro-environmental thinking and home pro-environmental behavior compared with work pro-environmental behavior (52 vs. 30%). A William's *t*-test for non-independent correlations was used to compare the difference in strength for each correlation and showed this difference to be significant [$t_{obt}(323) = 5.83$, $p < 0.05$]. This suggests that the relationship between pro-environmental thinking and home behavior was stronger. The relationship between home and work pro-environmental behavior was also reliable (explained variance = 52%). This suggests that there was a degree of shared variance in pro-environmental behavior between contexts, but still a large proportion of variance that is not explained by people's cognitions and thus is attributable to other factors.

FIT variables and sustainability indicators

The relationships between FIT Integrity and the pro-environmental thinking and pro-environmental behavior scales were positive and significant ($r = 0.21$). The relationships were weak and explained a small proportion of the variance (4.4, 3.2, and 4.4% for pro-environmental thinking, home behavior and work behavior, respectively). Further analysis of each Constancy showed that Awareness was positively related to pro-environmental thinking ($r = 0.16$) but not performance of pro-environmental behaviors. The Balance Constancy positively related to pro-environmental behaviors performed at home ($r = 0.11$). Conscience was positively correlated with all three pro-environmental indicators (for pro-environmental thinking, $r = 0.20$; for home pro-environmental behavior, $r = 0.14$; for work pro-environmental behavior, $r = 0.19$). Fearlessness was positively related to performance of pro-environmental behavior at home ($r = 0.12$). The Self-Responsibility Constancy was related to pro-environmental thinking ($r = 0.11$). There were no relationships between Behavioral Flexibility and either pro-environmental thinking or pro-environmental behavior whether at home or at work (r ranged from 0.01 to 0.05).

Following on, partial correlations were conducted to explore whether the relationship between FIT Integrity and pro-environmental behavior was direct or was mediated by strength of pro-environmental thinking. The relationships between FIT Integrity and pro-environmental behavior performed at home and work whilst controlling for pro-environmental thinking were found to be non-significant [$r_{partial}(235) = 0.02$, $p = 0.69$; $r_{partial}(235) = 0.12$, $p = 0.07$, respectively]. This suggests that the relationship between FIT Integrity and pro-environmental behavior was indirect and somewhat dependent on strength of pro-environmental thinking.

Table 4 | Intercorrelations amongst the pro-environmental and FIT Profiler scales ($N = 325$).

Scale	1	2	3	4	5	6	7	8	9	10
(1) Thinking	–									
(2) Home behavior	0.72**	–								
(3) Work behavior	0.55**	0.72**	–							
(4) Integrity	0.21**	0.18*	0.21**	–						
(5) Awareness	0.16**	0.09	0.07	0.53**	–					
(6) Balance	0.08	0.11*	0.09	0.52**	0.02	–				
(7) Conscience	0.20**	0.14*	0.19**	0.60**	0.27**	0.03	–			
(8) Fearlessness	0.03	0.12*	0.10	0.49**	–0.05	0.24**	–0.05	–		
(9) Self-responsibility	0.11*	0.06	0.08	0.64**	0.28**	0.18**	0.23**	0.26**	–	
(10) Behavioral Flexibility	0.05	0.01	0.01	0.08	0.10	0.06	–0.04	0.08	0.04	–

$**p < 0.01$; $*p < 0.05$.
Thinking, pro-environmental thinking; Home bvr, home pro-environmental behavior; Work bvr, work pro-environmental behavior; S-Responsibility, Self-Responsibility; B-Flex, Behavioral Flexibility.

DISCUSSION

This study was the first to undertake an empirical investigation of the relationships between FIT variables and pro-environmental activity. It was a preliminary study. We used the FIT framework (Fletcher and Stead, 2000), a non-conventional framework that has received rather less empirical investigation than many other frameworks relating to behavior and behavior change. By taking this approach we wanted to test the possible relevance of a new theory of pro-environmental action and identify the personal characteristics that might support individuals in engaging with sustainability issues both cognitively and behaviorally.

The limited empirical research that already exists has explored the FIT framework in relation to health-related outcomes, specifically weight loss, stress, and family functioning (see Fletcher et al., 2011; Sharma, 2011). The research presented here has begun to elucidate the value of the FIT framework in a very different and timely domain – engagement with pro-environmental activity.

Specifically, there were reliable relationships between the FIT Constancies and the measures of pro-environmental thinking and behavior. The relationships with pro-environmental behavior were mediated by an individual's cognitive engagement with pro-environmental activity. In contrast, there were no relationships with Behavioral Flexibility. It is, however, noteworthy that the Behavioral Flexibility scores were low and did not extend beyond the mid-point of the scale.

The pattern of results tentatively indicates that personal FITness levels do relate to an individual's cognitive and behavioral engagement with pro-environmental activity. The mediated relationship between the FIT Constancies and pro-environmental behavior suggests that sustainability is both a psychological and a behavioral problem. In relation to these results, we suggest that those models that seek to explain pro-environmental behavior, and those that seek to encourage pro-environmental behavior change, should consider both the cognitive and behavioral dimensions of sustainability simultaneously and equally, rather than placing significant emphasis on one dimension at the detriment of the other.

In some ways, the FIT framework does allow us to look at both the cognitive and the behavioral characteristics that might relate to pro-environmental activity. The relationships found in our preliminary study suggest that an individual's cognitive Constancies are more influential than their degree of Behavioral Flexibility in determining current pro-environmental behavior. This does not mean, though, that being behaviorally flexible is unimportant or that behavior change approaches should only focus on developing people's cognitive engagement. Specifically, we have only shown here that Behavioral Flexibility does not correlate with established patterns of pro-environmental thinking or behavior. In retrospect, we perhaps should not have been too surprised by this. It may just indicate that people behave fairly habitually, whether or not their habits are pro-environmental. Indeed, the low distribution of Behavioral Flexibility scores suggests general patterns of behavior are fairly fixed. If this is the case more generally, then it will be important to focus interventions on enhancing the Behavioral Flexibility of the habitually "non-green," leaving the habitually "green" to continue in their largely sustainable behavioral routines.

We have already discussed how habits can support pro-environmental behaviors. It seems counterintuitive to disrupt the behavior patterns of those individuals who are habitually sustainable in their approach, simply to make them more flexible. They have, after all, established patterns of behavior that are pro-environmental. What we are suggesting, therefore, is that a sufficient level of Behavioral Flexibility might be more important for supporting individuals to change behavior to become more pro-environmental, than it is for them to be pro-environmental *per se*. This would suggest that enhancing Behavioral Flexibility might make it easier to turn non-green behaviors to green, a hypothesis that deserves further investigation. The purposeful development of Behavioral Flexibility might be a necessary pre-cursor to support individuals who are habitually non-green toward a more pro-environmental disposition and more sustainable behaviors.

Whether, in the pursuit of more sustainable behaviors, it will be necessary to target interventions at enhancing the cognitive Constancies, is an open question. Although enhanced cognitive Constancies were associated here with more pro-environmental thinking and behavior, it is just as possible that a change in behavior can prompt a change in thinking, as vice versa. The FIT framework (Fletcher and Stead, 2000) emphasizes the bi-directional relationship between people's cognitions and their behavior, and the DSD behavior change approach associated with the FIT framework seeks to direct development in both areas.

The FIT-DSD approach targets cognitions and behaviors both directly and indirectly through a structured change process based on habit reversal and (new) habit rehearsal. The indirect approach of the DSD intervention is characterized by an action-oriented stance in relation to change; it works by targeting behavior directly to leverage indirect changes in thinking. Specifically, the DSD approach encourages people to experiment with new behaviors, to try new and different ways of behaving in order to become more flexible. This, it is suggested (Fletcher and Stead, 2000), helps to expand the size of the behavioral repertoire. Through experimenting with new behaviors, people might be better equipped to weaken their existing habits (characterized by Fletcher and Stead as "habit-webs") and also encounter new experiences that could challenge current thinking (see Page and Page, 2011).

In consideration to the powerful role of habit in cognition and behavior, and in separating behaviors from cognition (Klöckner and Blöbaum, 2010) and intention (Armitage and Conner, 2001), the FIT-DSD model of behavior change targets behavior directly by getting people to act out new behaviors rather than getting them to think about performing these. This might help to overcome (by rendering them irrelevant) the value-action gap (Blake, 1999) and the thinking-action gap that are so often evident in efforts toward pro-environmental behavior change. At the same time, therefore, the FIT approach challenges the 'thinking trap' (Fletcher and Pine, 2013) of researchers who tend to overestimate the power of thinking and hence to underestimate the power of actions.

There have been some practical applications of the FIT Framework to a range of psychological and social outcomes including stress, weight loss, and family functioning (Fletcher and Stead, 2000; Fletcher et al., 2011; Sharma, 2011). Taking weight-loss as an example, the DSD approach invites participants to engage in a structured program of doing something different on a regular basis for a set period of time. Across the time period of the intervention, the focus is on the development and performance of new behaviors. Importantly, these habit reversal and habit rehearsal tasks are not necessarily focused on the behavior that is the target of change. For example, in a weight-loss intervention, there is no necessity for all, or for even a majority of, the novel behaviors to have anything to do with food and exercise. The driving credo is that habits are not independent from one another, but exist in a mutually supporting network of habit-webs (cf. Neal et al., 2006) and routines. By breaking down the distal habits (the fixed routines of daily life) that form the habit-web in which the proximal target habits (e.g., overeating) reside, the DSD programme seeks to enhance generic flexibility. It seeks to put people into a (psychological) place in which they can change anything about themselves, before attempting to change any particular habit. As such, it comprises behavioral experiments at a generic level, designed to reinforce the belief that flexibility and change are a defining feature of a true comfort zone.

But why might this approach be an appropriate alternative model of behavior and a practical framework for pro-environmental behavior change? In many ways pro-environmental behavior change presents a very different challenge for the FIT Framework and the DSD approach from those to which it has previously been applied. One obvious distinction concerns the personal relevance of the target outcome. It is easy to see why someone might subscribe to a target outcome that sees them losing weight, but less easy, perhaps, to see why someone who is not already cognitively predisposed would set sustainability as a target outcome. Another distinction concerns the number of different changes that are required to enhance the sustainability of individual lifestyles, and the required perseverance of these changes across multiple contexts and in the presence of different pressures, e.g., competing social norms. These characteristics make pro-environmental lifestyle change a particularly challenging goal on which to focus.

Based on the results of our preliminary research, there is the possibility that the FIT framework and associated DSD approach might offer a useful alternative perspective on pro-environmental action. The approach offered by the FIT framework is, by nature, generic, and has applicability to many different behavior types. It offers a different perspective on the personal characteristics that relate to pro-environmental activity and deliberately steers clear of some of the habits that researchers are starting themselves to develop in their efforts to come to a better understanding of pro-environmental behavior.

We are well aware that even this preliminary study is not without its limitations. As noted previously, the data were self-reported and included only individuals' perceptions of their environmental activities and levels of Behavioral Flexibility rather than objective measures. This raises potential limitations with regards to the accuracy of self-report data and the influence of self-serving bias (Schwarz, 1999), particularly in relation to the performance of sustainable actions in home and work contexts. Objective measures of both pro-environmental behavior and of Behavioral Flexibility are much more desirable and would, of course, offer a more reliable outcome (Huffman et al., 2014). It is, however, difficult to imagine a truly objective measure of Behavioral Flexibility that would not place enormous practical demands in terms of observing a given individual behaving in a variety of different contexts over time. The practicalities of such observation would render it unlikely that we could collect sufficient data to infer correlations and to analyze patterns in behavior. Objective measures of pro-environmental activities are more feasible, in as much as they can be extrapolated from proxy measures such as energy use, waste produced, travel modality and mileage, etc. However, as it was our intention to simply demonstrate the possible relevance of a new theory of pro-environmental action, then we think that self-reported data is sufficient in this instance. Many other studies in the area have employed similar methods (see Abrahamse et al., 2005; Osbaldiston and Schott, 2012).

We hope that the moderate sample size offers some reassurance that the results have a degree of validity and reliability. However, the relationships that we have evinced between FIT variables and pro-environmental activity are correlational rather than causal and, moreover, exhibit statistical relationships of only modest strength. We did not measure the relationships between alternative behavioral frameworks and theories and pro-environmental action, principally owing the large number of disparate measures that these alternative frameworks entail. We are not able to judge directly, therefore, the value of the FIT framework in comparison to other models. Nonetheless, based on these preliminary results, we can see that there is potential to explore further relationships between the FIT framework and pro-environmental activity in a more systematically comprehensive and validated way, and to consider further the value of the DSD approach in relation to pro-environmental behavior change. Our next steps, therefore, will be to undertake further empirical exploration of the relationship between FIT variables and pro-environmental activity in different samples and to compare these with the relationships between pro-environmental action and other psychological variables derived from alternative theories of behavior. By, we hope, confirming the statistical robustness of the relationships reported here, and by further exploring the value of the FIT framework in promoting practical action, we aim to encourage a degree of eclecticism in the psychological approaches to pro-environmental behavior change.

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