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# Virtual reality for neuropsychology and affective cognitive sciences: Theoretical and methodological avenues for studying human cognition

**Edited by**
Ali Oker, Florian Pecune and Jordi Vallverdu

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# Virtual reality for neuropsychology and affective cognitive sciences: Theoretical and methodological avenues for studying human cognition

**Topic editors**
Ali Oker — Université de Reims Champagne-Ardenne, France
Florian Pecune — University of Glasgow, United Kingdom
Jordi Vallverdu — Autonomous University of Barcelona, Spain

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EDITED AND REVIEWED BY
Ronan Boulic,
Swiss Federal Institute of Technology Lausanne, Switzerland

*CORRESPONDENCE
Ali Oker,
ali.oker@univ-reims.fr

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# Editorial: Virtual reality for neuropsychology and affective cognitive sciences: Theoretical and methodological avenues for studying human cognition

Ali Oker[1,2]*, Florian Pecune[3] and Jordi Vallverdu[4]

[1]Université de Reims Champagne-Ardenne, Reims, France, [2]EA6291 Laboratoire Cognition Santé, Société (C2S), Reims, France, [3]Laboratoire CNRS UMR 6033 SANPSY, Université de Bordeaux, Bordeaux, France, [4]Universidad Autónoma de Barcelona (UAB) ICREA Acadèmia, Barcelona, Spain

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Editorial on the Research Topic
Virtual reality forneuro psychology and affective cognitive sciences: Theoretical and methodological avenues for studying human cognition

The Research Topic presented here emphasizes the theoretical and methodological contributions of the use of virtual reality to study human cognition. At a first glance, the use of novel technologies, such as virtual reality can be seen only as broader means of providing richer and multimodal stimuli for experimental psychology. However, it should be stressed out that the introduction of virtual reality in the field represents a serious paradigm shift in cognitive sciences. When Wilhelm Wundt established the first laboratory at Leipzig University in 1879, namely "The Institute for Experimental Psychology", he deliberately created a separate space from other departments in which it could be possible to conduct experiments by isolating several parameters. Wundt was one of the first who recognized that behavior and even the subjective aspects of the mind itself can be observed according to independent variables created in the environment. Thus, he understood that in order to manipulate the variables that he created, he had to control other variables already present in the reality of this space. This is why a dark room was installed in this laboratory for performing psychophysical experiments on visual perception (Nicolas, 2005). This may seem insignificant by today's standards, but virtually what Wilhelm Wundt tried to do was the manipulation of the physical reality in which modified stimuli have been exposed to participants. His work made that psychology is furthermore established as a full-fledged empirical science.

More than a century after, technological advances in the field of computer sciences have also led to creating a new environment for a new kind of interface, interaction, and immersion: Virtual Reality. Following the democratization of technology, researchers in cognitive science found out that virtual reality can be a real asset for studying neuropsychology and affective cognition experimentally. The fact that it can create any familiar environment without limits (e.g., public transport, music theater, street . . . ) made it a pertinent technology for mental health studies. But more importantly, in virtual environments, researchers not only are able to manipulate everything, but they can also create new laws of physics, stimuli and objects that don't exist in the outside world. This makes the use of virtual environments a very important paradigm shift in the field of cognitive science. Therefore, virtual reality is also increasingly used in recent neuropsychological studies. Finally, thanks to its immersive and interactive nature, virtual environments are also being popular by the use of affective and reactive virtual agents in social cognition disorder studies (Brunet-Gouet et al., 2016).

Based on these observations, the Research Topic presented here is gathering familiar methodological tools in cognitive science and neuropsychology coupled to the use of virtual reality, virtual environments and virtual agents. A first line of contributions made the use of virtual reality with behavioral measures frequently performed in neuropsychology and cognitive science studies such as electroencephalography (EEG), eye-tracking, heart rate variability. For instance, Cuesta et al., provided a proof-of-concept to assess the potential of coupling virtual reality and EEG in aging individuals with subjective cognitive decline. They highlighted that, older adults did not suffer from cybersickness and reported positive user experience but also highlighted a significant improvement in working memory when comparing virtual intervention groups to the control group. Turbyne et al., studied parameters involved in mitigating acute pain by investigating whether affective and physiological responses to painful electrical stimulation differed between a first and a third person perspective in virtual reality. The results confirm that the participants reported significantly higher tension during the third person condition. In order to investigate authentic, fear responses from a holistic perspective, Kisker et al., provided an immersive experience in which they built a physical replica of a cave while participants explored with a fearful or a neutral version of it in virtual reality. During the experiment, electrophysiological correlates of fear-related approach and avoidance tendencies, such as frontal alpha asymmetries (FAA) were evaluated for the first time for this kind of immersive conditions related to authentic fear.

The second line of contributions consisted of wellbeing and mental health issues. Batistatou et al., used virtual reality to test the impact of colorful floor markings on the spontaneous speed of walking, gaze behavior recorded by eye-tracking, as well as perceived changes in and physiological measures of affective states. Their findings suggest that colors may be a powerful tool to trigger alertness and pleasure in gray urban cities. On the matter of improving wellbeing, Pavic et al., reviewed the scientific literature on how to foster positive emotions through virtual reality. They found out that the positive virtual reality experience consists of applications for relaxation, stress and pain management, motivation for physical activities, and gives promising results for apathy treatment in elderly users. Chaby et al., also investigated how and why virtual patients can be used in psychiatry and geriatrics in order to train healthcare professionals in social skills required to interact with patients. They also propose recommendations, best practices and uses for the design, conduct and evaluation of virtual patient training sessions. Regarding virtual characters, Stallman et al. , proposed a new and innovative methodology article in which they provided a description of the development of a novel paradigm designed to test the efficacy of social emotion regulation with an embodied virtual agent and its virtual environment, and how to anticipate results from typically developing and autistic youth populations. Finally, Oker shed some light on the link between neural underpinnings of embodied social cognition and virtual agents' pertinence for experimental studies in cognitive psychopathology depicting social cognition impairments.

While it is not the first nor the last time in the literature, studies presented in this Research Topic show clearly how virtual reality and virtual agents are pertinent tools for studying neuropsychology and affective cognitive science. We predict that we are just in the beginnings of a real paradigm shift in the field and, following further democratization of the head mounted displays, virtual reality will become an acclaimed and inevitable tool in psychology labs in the next decade.

## Author contributions

AO wrote the first draft. All authors have supervised the manuscript.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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Brunet-Gouet, E., Oker, A., Martin, J. C., Grynszpan, O., and Jackson, P. L. (2016). Editorial: Advances in virtual agents and affective computing for the understanding and remediation of social cognitive disorders. *Front. Hum. Neurosci.* 9, 697. doi:10.3389/fnhum.2015.00697

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ORIGINAL RESEARCH
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# Affective and Physiological Responses During Acute Pain in Virtual Reality: The Effect of First-Person Versus Third-Person Perspective

*Collin Turbyne**, *Pelle de Koning, Dirk Smit and Damiaan Denys*

*Academic Medical Center, Department of Psychiatry, University of Amsterdam, Amsterdam, Netherlands*

**Background:** Virtual reality (VR) has been previously shown as a means to mitigate acute pain. The critical parameters involved in the clinical efficacy of mitigating acute pain from different perspectives remains unknown. This study attempted to further deconstruct the critical parameters involved in mitigating acute pain by investigating whether affective and physiological responses to painful stimuli differed between a first and a third person perspective in virtual reality.

**Methods:** Two conditions were compared in a repeated-measures within subject study design for 17 healthy participants: First person perspective (i.e., where participants experienced their bodies from an anatomical and egocentric perspective) and third person perspective (i.e., where participants experienced their bodies from an anatomical perspective from across the room). The participants received noxious electrical stimulation at pseudorandom intervals and anatomical locations during both conditions. Physiological stress responses were measured by means of electrocardiography (ECG) and impedance cardiography (ICG). Subjective scores measuring tension, pain, anger, and fear were reported after every block sequence.

**Results:** There were no significant differences in physiological stress responses between conditions. However, the participants reported significantly higher tension during the third person condition.

**Conclusion:** Relative to a third person perspective, there are no distinct physiological benefits to inducing a first person perspective to mitigate physiological stress responses to acute pain in healthy individuals. However, there may be additional clinical benefits for doing so in specific clinical populations that have shown to benefit from relaxation techniques. Further research is needed in order to refine the clinical utility of different perspectives during virtual reality immersions that serve to act as a non-pharmacological analgesic during acute pain.

**Keywords: virtual reality, first person perspective, third person perspective, affective psychophysiology, acute pain analgesia**

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*Jordi Vallverdu,*
*Universitat Autònoma de Barcelona, Spain*

***Reviewed by:***
*Aryabrata Basu,*
*Emory University, United States*
*Lynne Sneddon,*
*University of Gothenburg, Sweden*

****Correspondence:***
*Collin Turbyne*
*c.a.turbyne@amsterdamumc.nl*

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## INTRODUCTION

Pain can be defined as an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage (IASP, 2017). Currently, acute pain is largely relieved using pain-medication, however, these analgesics also have unwanted side effects which often requires additional, complicated, considerations for their administration (Alford et al., 2006). In order to better address these concerns, there has recently been an increased demand for non-invasive methods that have the potential to be self-administered. One candidate that is being increasingly explored in acute pain research is virtual reality. To date, a common class of techniques used to mitigate the experience of acute pain is by inducing a body illusion.

A body illusion can be defined as any event where an individual's physical body has been perceptually modified in order to gain some further understanding of their own-body perception. The ability to modulate acute pain sensations have been explored in several different classes of body illusions; most commonly in body distortion (Mancini et al., 2011; Martini et al., 2013; Romano and Maravita, 2014; Matamala-Gomez et al., 2020) and body ownership (Longo et al., 2009; Hänsell et al., 2011; Martini et al., 2015) paradigms using both virtuality technologies and non-virtual (ex. mirrors) instruments. The use of virtuality technologies is becoming more ubiquitous in body illusion research due to the enhanced ability of being able to manipulate information in ways that are otherwise not possible. An example of such an advantage can be seen in another emerging class of body illusions known as out of body experiences (OBE), whereby the perceived location of the self is separated from the actual location of the physical self (Ehrsson, 2007; Lenggenhager et al., 2007; Blom et al., 2014; Pfeiffer et al., 2014). These illusions involve the individual viewing a third person perspective of themselves from a first person perspective.

Body illusions, regardless of class, are induced and sustained through the use of multisensory signal integration. The dynamics between this multisensory interplay of manipulating the sense of body ownership, agency, and the experience of acute pain still remains unclear for several reasons. From a more fundamental stance, it is still not clear what role perspective plays in facilitating both the affective and physiological responses to a noxious stimulus. Moreover, there is still a lack of clarity surrounding the understanding of autonomic responses to experimentally induced painful stimulation. Results from a previous review that sought to clarify the physiological component of the acute pain response to experimentally induced painful stimulation identified several important suggestions for future research which included how cognitive and affective constructs are under-investigated and warrant more attention and that studies should include measures that specifically assess both sympathetic and parasympathetic responses (Kyle and McNeil, 2014).

Currently, one of the major competing theories attempting to explain the analgesic potential of virtual reality postulates that virtual reality is able to effectively distract an individual from noxious stimuli (Hoffman et al., 2000; Hoffman et al., 2001; Schneider et al., 2004; Gershon et al., 2004; Hoffman et al., 2011). Furthermore, it has been hypothesized that the more attention demanding the virtual immersion is, the better it is for reducing pain (Lier et al., 2020). The purpose of this study aims to further deconstruct the basis of body illusions by further examining how perspective contributes to the affective and physiological experience of acute pain. In order to test this, we compared a first and third person perspective of the self during virtual immersion while administering noxious electrical stimuli. In the first person condition, there was visuomotor congruency between the visual information of the participants' virtual embodiment and their bodily movements which they were asked to attend to (**Figure 1A**). However in the third person condition, the participants still experienced their bodily movements from an anatomical perspective but visually perceived themselves from a front facing profile from across the room. Therefore in this condition, there was incongruent, conflicting, visuomotor information between the visual information of their virtual embodiment and their bodily movements which they were asked to attend to (**Figure 1B**). One of the main differences with the extant literature on the effect of interaction in virtual environments (VE) is that we did not provide any visual cues in our VEs that could provide expectancy effects that could interfere or interact with the perspective, as previous literature has shown that environmental interaction compared to no interaction is significantly more analgesic (Lier et al., 2020). In line with the theory of attentional demand (Hoffman et al., 2019), we hypothesized that the incongruent visuomotor information experienced during the third person perspective would demand an increase in attentional capacity and therefore further distract the individuals from the painful stimuli, resulting in a relatively lower physiological stress response and lower subjective ratings compared to the first person perspective.

## METHODS

### Participants

We recruited 17 healthy adults to participate in this research. Testing took place in the Psychiatry Department in the Amsterdam University Medical Centre (Amterdam UMC) (Amsterdam, Netherlands). Participants were included on the basis of having no previous DSM-V diagnosis of a mental disorder and no previous neurological diagnosis or complaints of having chronic pain or somatosensory hypersensitivity. This study was reviewed and approved by the medical ethical committee of the Amsterdam UMC. The participants provided their written informed consent in order to participate in this study. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### Virtual Environment and Equipment

The VE was presented on an HMD (Oculus Rift DK2) from both a first person and fixed third person perspective. The VE in the first person perspective depicted a video image of what the participants saw from their natural perspective, which

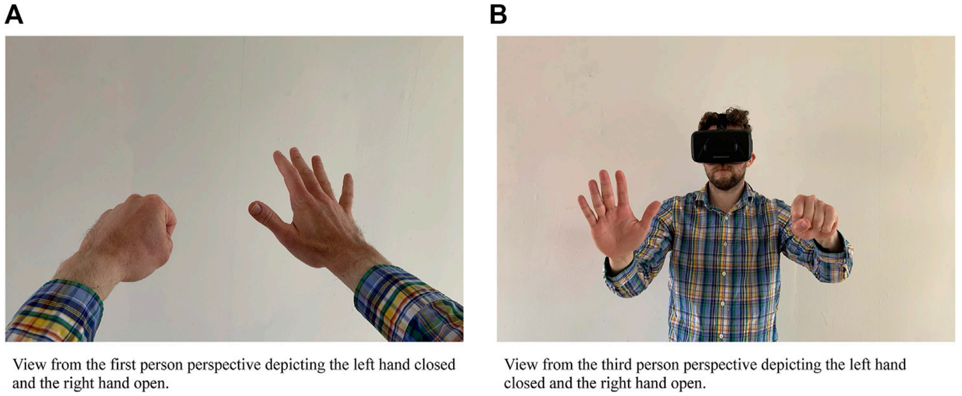


**FIGURE 1 |** Visualization for both experimental conditions.

consisted of them sitting in a chair in an empty room with white walls and a dark floor. The VE in the third person perspective depicted the individuals' front facing profile as they sat on a chair in an empty room with white walls and a dark floor. The minimalistic design of these VEs allowed us to better study the effects of perspective on distraction by removing unnecessary environmental objects and interactions that could have further impacted the participants' experience. In both conditions, the participants saw their movements from an anatomical reference. The VEs were created from a video feed which came from a stereoscopic camera (Zed Mini) that was mounted either on the front of the HMD or on a camera tripod in front of the individual. The VE ran within a game engine (Unity 3D).

## Physiological Measurements

We measured three physiological indicators during the exposure to assess the participants' stress response *via* autonomic nervous system (ANS) activity by means of electrocardiography (ECG) and impedance cardiography (ICG) using an ambulatory physiological recording device (VU-AMS, VU University). We adhered to the operational use of the device according to the manual (Vrije Universiteit, 2019). Our signals of interest included heart rate (HR), respiratory sinus arrhythmia (RSA), and pre-ejection period (PEP). HR is an indicator of combined parasympathetic and sympathetic control (Akselrod et al., 1981). RSA is a naturally occurring variation in HR during a respiration cycle and has been shown to be a reliable way to assess parasympathetic control (Katona and Jih, 1975). PEP is the time interval between electrical stimulation of the ventricles and the opening of the aortic values, which measures sympathetic control of cardiac activity (Newlin and Levenson, 1979; Berntson et al., 2004). VUDAMS software version 4.0 was used to pre-process the physiological data as described in the manual (Vrije Universiteit, 2019). After the data was visually inspected and manually corrected by an independent researcher, we could derive the inter beat interval (IBI) times series and respiration signals from the ECG and ICG signals. The different periods of the script were labeled using the visual interface within the DAMS environment. Heart rate (HR) was attained directly from the IBI time series. Respiratory sinus arrhythmia (RSA) was obtained by combining the reparation signals with the IBI time series using the peak valley method. For our analysis, we are reporting the "RSA-zero" mean variable, meaning the RSA value was automatically set to be zero for breaths that the software detected as having an invalid RSA. In order to be as conservative as possible, we discarded a dataset if more than 50% of the data was missing. This could be due to hardware malfunction or being manually set to missing because the researchers and independent researcher collectively agreed that a segment of data could not be reliably analyzed. Pre-ejection period (PEP) was calculated as the time from the onset of the Q-wave in the ECG to the opening of the aortic valves, selected by the B-point in the ICG signal.

## Pain Stimuli

Four electrodes from a stimulation device (ENERGY Light) were positioned on the participants' legs. Electrodes were placed above the knee on the right leg, below the knee on the right leg, above the knee on the left leg, and below the knee on the left leg. Before beginning the test, each of the individual current intensities were adjusted on an individual-to-individual as well as a region-by-region basis to be experienced as moderately painful. This was determined by gradually increasing the intensity of the current until the individual reported a moderate level of discomfort. These stimuli were administered remotely, with the researcher being out of view from the participant, and silently. This approach helped us to mitigate any potential effects due to stimulus expectancy.

## Verbal Likert Scale

Subjective levels of pain were obtained by administering a verbal Likert scale (VLS). The range for the scaled questions was from 1–5 with (1 not at all—5 extreme). The scaled questions addressed how tense they were, how much pain they were in, how fearful they were, and how angry they were.

## Procedure

This study consisted of two conditions, a first person perspective and a third person perspective, using a repeated measures within-subjects design. For a complete overview of the experimental

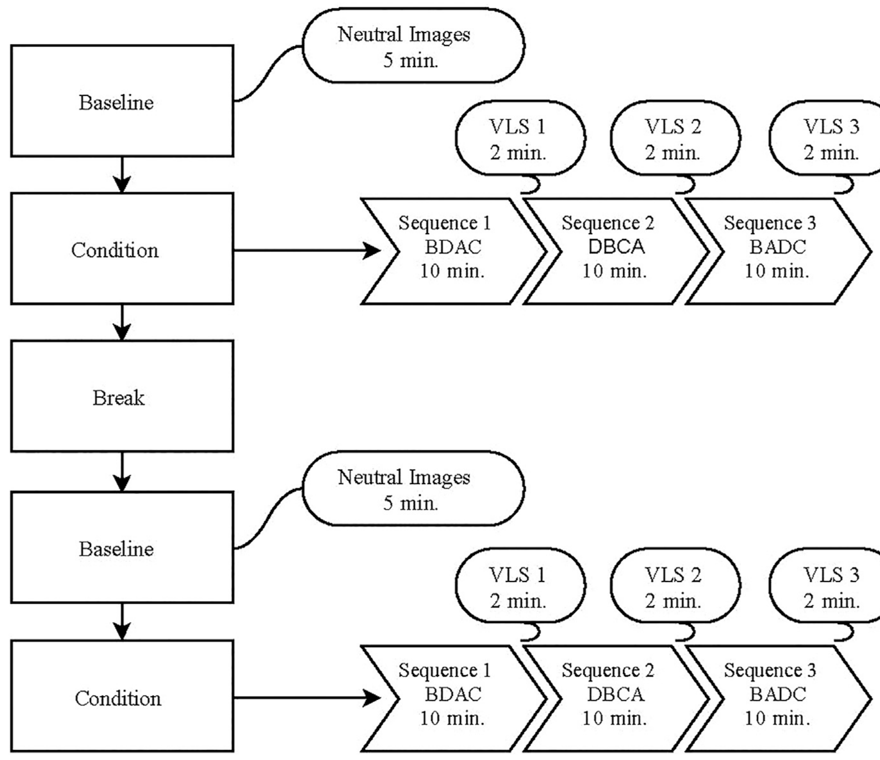


**FIGURE 2 |** A complete overview of the experimental design.

design, please see **Figure 2**, which has been adopted and modified from the method section of previous research (Turbyne et al., 2021). Before starting either condition, the participants underwent a relaxation phase which presented a series of five different neutral images taken from a validated database (Lang et al., 2008) which were adopted for use in an HMD at a rate of one stimulus per minute. We synchronized the onset of the physiological recordings with the presentation of these images in order to prevent false detections, which established the baseline for our analysis. This phase was directly followed by an immersion phase which allowed the participants to acclimate themselves within the virtual environment in which they were encouraged to explore their bodies by looking at themselves and moving their limbs while being seated. This phase lasted for a total of 5 min. After this phase we initiated either the first or third person condition. We presented a total of three sequences per condition, each of which contained four blocks that corresponded to an anatomical region. The anatomical regions were: A) above the left knee, B) below the left knee, C) above the right knee, and D) below the right knee. Each block within every sequence was pseudo-randomly presented, such that each block was represented in that sequence and that no block could not be repeated back-to-back either in that sequence or the subsequent sequence. The inter-sequence interval was set to 2 min, which allowed us to mitigate any potential carry over effects from the previous sequence, as well as allow us ample time to administer a VLS. Each block contained 6 stimuli, with each stimulus lasting 0.2 ms. The inter-stimulus interval was set to 20 s, which allowed us to obtain a clear and analyzable physiological signal. After completing the first condition, the participants removed the HMD before beginning the subsequent condition. The inter-condition interval was variable amongst subjects, with a maximum period of 30 min. The purpose of the inter-condition interval was to ensure that the participant did not experience any simulation sickness before beginning the subsequent condition. The conditions were counterbalanced between participants. The verbal explanation to the participants prior to starting each condition was the following: "During this condition, I will stimulate different areas of your legs. Please try to visually focus on yourself as I do this. You are allowed to move around freely while remaining seated".

## Statistical Analysis

We conducted a generalized estimating equation (GEE) analysis to examine the between condition differences in physiological measurements from baseline to pain provocation ($\Delta$HR, $\Delta$RSA, $\Delta$PEP) as well as VLS scores. GEE models can be used to analyze repeated measures data with binary, ordinal, or continuous outcomes (Zeger et al., 1988; Liang and Zeger, 1993). For our GEE analysis we selected an exchangeable correlation structure. The model's fixed effects consisted of main effects for stimulus region and perspective, as well as their interaction. For the physiological parameters $\Delta$HR, $\Delta$RSA, and $\Delta$PEP, a Gaussian link function was specified. For the ordinal VLS

**TABLE 1** | Results of exchangeable correlation generalized estimating equation for physiological measurements from baseline to pain provocation.

| | Wald Chi-Square | Type III df | P |
|---|---|---|---|
| ΔPEP | | | |
| Perspective | 1.115 | 1 | 0.291 |
| Stimulus region | 3.692 | 3 | 0.297 |
| Perspective*stimulus region | 5.294 | 3 | 0.152 |
| ΔRSA | | | |
| Perspective | 1.873 | 1 | 0.171 |
| Stimulus region | 7.170 | 3 | 0.067 |
| Perspective*stimulus region | 4.216 | 3 | 0.239 |
| ΔHR | | | |
| Perspective | 3.115 | 1 | 0.078 |
| Stimulus region | 16.909 | 3 | 0.001 |
| Perspective*stimulus region | 2.291 | 3 | 0.514 |

*ΔPEP = Change in pre-ejection period from baseline to pain provocation.*
*ΔRSA = Change in respiratory sinus arrhythmia from baseline to pain provocation.*
*ΔHR = Change in heart rate from baseline to pain provocation.*

scores, a logistic function was used. SPSS software version 26 was used to perform the GEE analysis. We Bonferroni corrected the obtained $p$-values for the number of dependent variables included in the repeated-measures GEE models; we multiplied $p$-values by three for the physiological indicators and by four for the VLS data.

## RESULTS

Physiological data was excluded for six participants due to large sections of missing data that was found to be caused by the electrodes losing contact sporadically throughout the experiment, leaving 11 subjects for analysis. As shown in **Table 1**, the GEE analysis revealed that perspective and stimulus region were not statistically significant predictors for ΔPEP [(perspective (*Wald* $\chi$ = 1.115, *df* = 1, $p$ = 0.291)] [stimulus region (*Wald* $\chi$ = 3.692, *df* = 3, $p$ = 0.297)] [perspective*stimulus region (*Wald* $\chi$ = 5.294, *df* = 3, $p$ = 0.152)] or ΔRSA [[perspective (*Wald* $\chi$ = 1.873, *df* = 1, $p$ = 0.171)] [stimulus region (*Wald* $\chi$ = 7.170, *df* = 3, $p$ = 0.067)] [perspective*stimulus region (*Wald* $\chi$ = 4.216, *df* = 3, $p$ = 0.239)]. However, for ΔHR, while there were no significant main effects for perspective [*Wald* $\chi$ = 3.115, *df* = 1, $p$ = 0.078] or an interaction effect between perspective and stimulus region [*Wald* $\chi$ = 2.291, *df* = 3, $p$ = 0.514], there was a significant main effect for stimulus region (*Wald* $\chi$ = 16.909, *df* = 3, $p$ = 0.001, Bonferroni-corrected $p$ = 0.003) (**Figure 3**). The main effect of perspective for ΔHR, while not significant, was approaching significance. In order to test if we had enough power, we performed a post-hoc sensitivity analysis using G*Power for repeated measures with the following settings: alpha = 0.0166, power = 0.80, sample size = 11, number of measurements = 12, and a correlation among repeated measures = 0.357. We were able to detect only large effects (Cohen's $d$ = 0.65).

The mean ratings for the individual questionnaire items are shown in **Figure 4**. When comparing means for VLS scores between conditions, pain, tension, anxiety, and anger were 2.0 (SD = 0.935), 1.82 (SD = 1.158), 1.48 (SD = 0.972), and 1.67 (SD = 1.051) during the first person condition and 2.12 (SD = 0.927), 2.18 (SD = 1.103), 1.61 (SD = 0.788), 1.55 (SD = 0.794) during the third person condition, respectively. As shown in **Table 2**, perspective and stimulus region were not statistically significant predictors for pain [perspective (*Wald* $\chi$ = 0.271, *df* = 1, $p$ = 0.602)] [stimulus region (*Wald* $\chi$ = 2.409, *df* = *1*, $p$ = 0.121)] [perspective*stimulus region (*Wald* $\chi$ = 2.042, *df* = 1, $p$ = 0.153)], anxiety [perspective (*Wald* $\chi$ = 1.682, *df* = 1, $p$ = 0.195)] [stimulus region (*Wald* $\chi$ = 0.006, *df* = *1*, $p$ = 0.938)] [perspective*stimulus region (*Wald* $\chi$ = 0.147, *df* = 1, $p$ = 0.702)], or anger [perspective (*Wald* $\chi$ = 0.085, *df* = 1, $p$ = 0.771)] [stimulus region (*Wald* $\chi$ = 0.618, *df* = *1*, $p$ = 0.432)] [perspective*stimulus region (*Wald* $\chi$ = 0.621, *df* = 1, $p$ = 0.431)]. However, for tension while there were no significant main effects for stimulus region (*Wald* $\chi$ = 0.025, *df* = 1, $p$ = 0.873) or an interaction effect between perspective and stimulus region [*Wald* $\chi$ = 1.073, *df* = 1, $p$ = 0.300], there was a significant main effect for perspective [*Wald* $\chi$] = 6.449, *df* = 1, $p$ = 0.011, Bonferroni-corrected $p$ = 0.044).

## DISCUSSION

The goal of this study was to investigate whether perspective can differentially effect the affective and physiological responses to acute

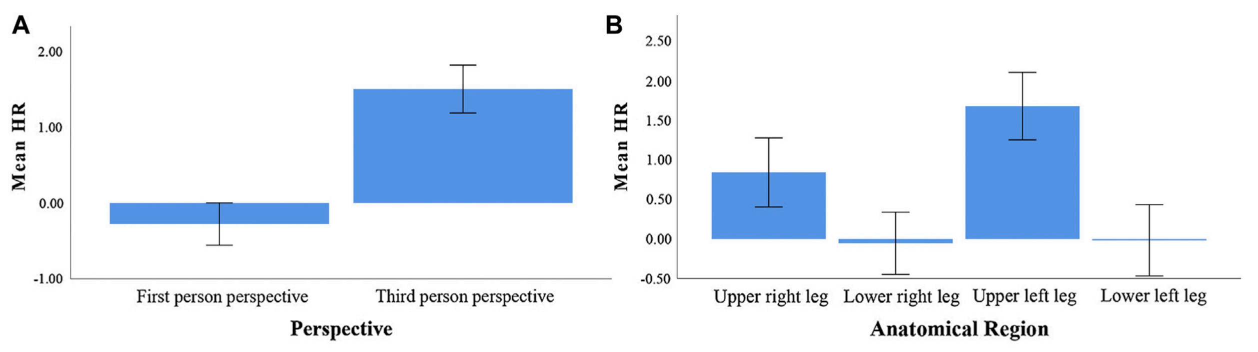


**FIGURE 3** | Mean HR for perspective **(A)** shows that third person perspective scores higher, which did not reach significance (p = 0.078). Anatomical region **(B)** showed a main effect with higher HR for upper stimulation region, which was significant (p = 0.001). Error bars are 95% CI.

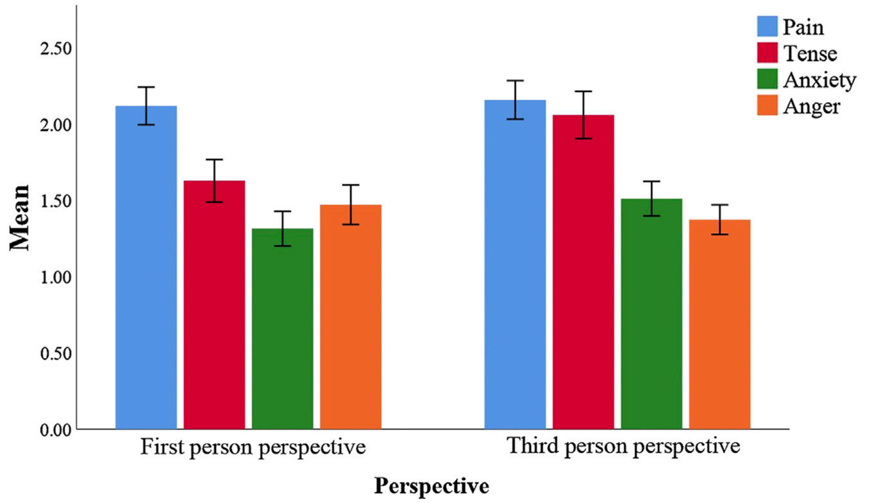


**FIGURE 4 |** Mean VLS scores for the first person **(left)** and third person **(right)** conditions. Error bars are 95% CI.

pain in virtual reality. This was investigated by comparing a modified body representation from a third person perspective, which consisted of incongruent visuomotor information between the visual information of the participants' virtual embodiment and their bodily movements, with an unmodified body representation from a first person perspective. We hypothesized that the third person condition would elicit a relatively lower physiological stress response and subjective report scores compared to the first person condition.

The results from our exploratory analyses showed no differences in physiological stress responses between perspectives or any interaction effects between perspectives and stimulus regions. However, we did find a significant main effect for stimulus region in ΔHR. This measure alone is not informative enough to be able to determine whether or not there is a stress response or what the magnitude of a potential stress response may be. HR is used more-so as a secondary measure to determine whether or not there is a stress response due to the fact that it is both a sensitive measure and that it only reflects the combined sympathetic and parasympathetic activity. Because we were unable to observe any significance for either PEP or RSA, this leaves us unable to determine what this difference in HR actually reflects. Arguably, this effect could be stronger if we added repetitions, per subject, to the data in order to increase the power, although this would likely be ineffective due to the fact that our within-effect already has eight repeats, being four repeats per condition times both perspectives. Adding additional repetitions would have also expanded the total length of the experiment, including setup time, to over 4 h which is not feasible from a practical stance, while also inducing trend effects from such a lengthy recording. In terms of affective responses, participants indicated low mean subjective scores for both conditions. However, individuals experienced significantly more tension in the third-person perspective compared to the first-person perspective. These results highlight the complex relationship of how specific states of emotion experienced during acute pain influence the underlying physiology of its perception. Evidence from a systematic review has shown how relaxation can benefit pain outcomes (Kwekkeboom and Gretarsdottir, 2006). Furthermore, previous meta-analytic evidence suggests that relaxation techniques are effectively able to reduce pain in cancer patients with acute pain (Luebbert et al., 2001). Therefore, while reduced tension had no effect in the healthy population we tested, the use of a first person perspective may be more advantageous to mitigate acute pain in certain clinical populations that have been found to further benefit from relaxation techniques.

In the current research we were unable to observe whether tension, i.e., mental stress, affected how the individuals visually attended to each condition. Previous research has shown that focused attention can mitigate pain (Roelofs et al., 2004). This could be further explored through the use of eye tracking during immersion, as previous research has found that eye tracking can be used to assess involuntary attentional consequences of pain (Schmidt et al., 2018). Therefore, future research with a similar design should seek to use virtuality headsets with integrated eye tracking in order to better determine the relationship between perspective, tension/relaxation, and the physiological stress response to acute pain.

**TABLE 2 |** Results of ordinal logistic generalized estimating equation for verbal Likert Scale data.

| | Wald Chi-Square | Type III df | P |
|---|---|---|---|
| Pain | | | |
| Perspective | 0.271 | 1 | 0.602 |
| Stimulus region | 2.409 | 1 | 0.121 |
| Perspective*stimulus region | 2.042 | 1 | 0.153 |
| Tension | | | |
| Perspective | 6.449 | 1 | 0.011 |
| Stimulus region | 0.025 | 1 | 0.873 |
| Perspective*stimulus region | 1.073 | 3 | |
| Anxiety | | | |
| Perspective | 1.682 | 1 | 0.195 |
| Stimulus region | 0.006 | 1 | 0.938 |
| Perspective*stimulus region | 0.147 | 1 | 0.702 |
| Anger | | | |
| Perspective | 0.085 | 1 | 0.771 |
| Stimulus region | 0.618 | 1 | 0.432 |
| Perspective*stimulus region | 0.621 | 1 | 0.431 |

Another explanation for why we did not find any significant effects of perspective for physiological stress responses could be due to our noxious stimulus selection and administration. While previous research has suggested that both heat and electrical noxious stimuli have been found to be comparable to each other in terms of their efficacy to elicit an acute pain response (Jiang et al., 2019) individual differences towards different types of painful stimuli will invariably occur. In our paradigm, four out of the seventeen participants had to max out the stimulation intensity of the device in order to achieve a self-reported moderate level of pain. It is reasonable to suggest that, due to individual differences, people naturally separate themselves into being relatively higher and lower responders to specific types of noxious stimulation. In order to better understand the potential analgesic effects of perspective, researchers should seek to administer tailored stimuli on an individual-to-individual basis. By integrating different types of noxious stimuli with different intensity levels into single research designs, researchers can begin to foster a classification system specific to different perspectives.

It should also be mentioned that while our results may be due to a small sample size, they may also be due to the subtlety of our manipulation. The only physiological indicator that was approaching significance for a main of effect of perspective was ΔHR and we were only able to establish large effect sizes in our sensitivity analysis. In a typical sense, this is insufficient, as it is desirable to also be able to detect other effect sizes. Contrastingly, clinical utility is contingent on being able to detect large effect sizes. It is possible that the absence of a difference in perspective could be due to allowing participants to freely initiate the movements of their own body while remaining seated. Because of this, individuals tended to move less over the duration of the experiment which may have diminished the strength of the manipulation by reducing the frequency of body ownership updates on body representation. Therefore, future research should seek to examine whether a stronger physiological/affective response can be observed if participants initiate body movements more frequently, which can be tested by having the participants perform pre-specified movements at specific time intervals.

Finally, we did not explicitly evaluate body ownership *via* subjective reporting (i.e., do you believe that this body is your own?). While our main intention was to assess the effect of perspective, which by definition implies modifying body representation, we are unable to conclusively determine whether or not our observations were due to perspective alone or if they were also influenced by the possibility that certain individuals felt that they did not own the body they were perceiving. As such, future research that seeks to further disentangle the effects of perspective on acute pain should include measures that directly assess body ownership.

## CONCLUSION

There are no significant differences between perspectives or anatomical regions for physiological stress responses to noxious electrical stimulation that could be observed in the current study. Despite this, participants were significantly more tense during the third person perspective. Our findings reveal that there are no clinical benefits for modifying a healthy individual's perspective during the experience of acute pain. However, there may still be clinical benefits for modifying an individuals perspective for specific patient populations that have been found to benefit from relaxation techniques. Our findings outline specific considerations that future research should consider in order to more fully understand the extent to which perspective may influence affective and physiological responses to acute pain in virtual reality pain reduction paradigms.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors upon reasonable request.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by METC Amsterdam UMC. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

CT: Conception and design, data acquisition, data analysis, interpretation of the data, drafting the original article, editing, revision. PK: Revising original article for important intellectual content. DS: Data analysis, interpretation of the data. DD: Final approval of the version published, accountable for the article to ensure that all questions regarding the accuracy and/or integrity of the study are investigated and resolved.

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# Authentic Fear Responses in Virtual Reality: A Mobile EEG Study on Affective, Behavioral and Electrophysiological Correlates of Fear

*Joanna Kisker*[1*†], *Leon Lange*[2†], *Kira Flinkenflügel*[3], *Michael Kaup*[3], *Nils Labersweiler*[3], *Falk Tetenborg*[3], *Paula Ott*[3], *Christopher Gundler*[4], *Thomas Gruber*[1], *Roman Osinsky*[2] and *Benjamin Schöne*[1]

[1]Experimental Psychology I, Institute of Psychology, Osnabrück University, Osnabrück, Germany, [2]Differential Psychology & Personality Research, Institute of Psychology, Osnabrück University, Osnabrück, Germany, [3]Institute of Psychology, Osnabrück University, Osnabrück, Germany, [4]Institute of Cognitive Science, Osnabrück University, Osnabrück, Germany

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**Edited by:**
Florian Pecune,
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United Kingdom
Mary C. Whitton,
University of North Carolina at Chapel Hill, United States

***Correspondence:**
Joanna Kisker
joanna.kisker@uni-osnabrueck.de

†These authors share first authorship

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Fear is an evolutionary adaption to a hazardous environment, linked to numerous complex behavioral responses, e.g., the fight-or-flight response, suiting their respective environment. However, for the sake of experimental control, fear is mainly investigated under rather artificial laboratory conditions. The latter transform these evolutionary adaptions into artificial responses, like keystrokes. The immersive, multidimensional character of virtual reality (VR) enables realistic behavioral responses, overcoming aforementioned limitations. To investigate authentic fear responses from a holistic perspective, participants explored either a negative or a neutral VR cave. To promote real-life behavior, we built a physical replica of the cave, providing haptic sensations. Electrophysiological correlates of fear-related approach and avoidance tendencies, i.e., frontal alpha asymmetries (FAA) were evaluated. To our knowledge, this is the first study to simultaneously capture complex behavior and associated electrophysiological correlates under highly immersive conditions. Participants in the negative condition exhibited a broad spectrum of realistic fear behavior and reported intense negative affect as opposed to participants in the neutral condition. Despite these affective and behavioral differences, the groups could not be distinguished based on the FAAs for the greater part of the cave exploration. Taking the specific behavioral responses into account, the obtained FAAs could not be reconciled with well-known FAA models. Consequently, putting laboratory-based models to the test under realistic conditions shows that they may not unrestrictedly predict realistic behavior. As the VR environment facilitated non-mediated and realistic emotional and behavioral responses, our results demonstrate VR's high potential to increase the ecological validity of scientific findings (video abstract: https://www.youtube.com/watch?v=qROsPOp87I4&feature=youtu.be).

**Keywords: authentic fear, virtual reality, mixed reality, mobile EEG, frontal alpha asymmetry, fear behavior**

## INTRODUCTION

The most salient stimuli that instantly draw attention are biologically relevant stimuli ensuring survival: nutrition, reproduction, and physical dangers (Carretié et al., 2012; Carboni et al., 2017). Among these, threats to physical integrity most inevitably jeopardize survival and immediately trigger complex responses, like the fight-or-flight response (Cannon, 1929). Hence, fear has been extensively investigated ever since (e.g., Fanselow, 1994; LeDoux 1998, 2014; Debiec and LeDoux, 2004; Blanchard and Blanchard, 1969). Several laboratory setups have been used over time to induce fear-related responses under laboratory conditions. One of the most prominent and efficient procedures for fear induction is classical conditioning (e.g., LeDoux, 1998; Jarius and Wildemann, 2015). This method has proven to be successful innumerable times in generating fear of a stimulus that was previously not frightful, assessed by typical fear responses to the conditioned stimulus, such as the startle reflex (e.g., Brown et al., 1951; Grillon and Ameli, 2001). However, conditioning paradigms require laboratory fear acquisition in order to examine fear responses (e.g., LeDoux, 1998), and mostly take only single components of the reaction detached from the overall reaction into account, e.g., the startle reflex, to guarantee high internal validity. More naturalistic assessments are based upon pre-existing fear, for example in behavioral avoidance tasks (BAT). BATs are conventionally used in exposure therapies to estimate the severity of phobias and the treatment's efficacy (see e.g., Bernstein and Nietzel, 1973; Rinck and Becker, 2007). In clinical assessments, BATs are regularly carried out *in vivo*, and therefore allow for holistic responses to the frightful stimulus (e.g., Bernstein and Nietzel, 1973; Koch et al., 2002; Deacon and Olatunji, 2007). However, clinical assessments are indicative of deficient or altered emotional regulation, rather than natural fear reactions (e.g., Hermann et al., 2009; Cisler et al., 2010; Lanius et al., 2010). In contrast, non-clinical applications of BATs broadly rely on finite response options and stimuli, such as pressing a key or pulling a joystick to indicate the urge to avoid or approach an aversive stimulus (e.g., Heuer et al., 2007; Hofmann et al., 2009; Krieglmeyer and Deutsch, 2010). These rather artificial setups neglect that fear is a multidimensional response to a holistic environment and associated with complex behavioral programs, such as the fight-or-flight response to immediate threat (e.g., Cannon, 1929; Lynch and Martins, 2015; Teatero and Penney, 2015).

The complexity and multidimensionality characteristic of real-world experiences can be simulated by sophisticated virtual reality (VR) setups (Slater and Sanchez-Vives, 2016; Parsons, 2019; Pan and Hamilton, 2018; Schöne et al., 2020). In particular, VR offers high levels of sensory cues and fidelity of the virtual environment (VE); (Dan and Reiner, 2017; Riva et al., 2019), resembling a multisensory 3D-environment (Cabeza and Jacques, 2007; Pan and Hamilton, 2018; Parsons, 2019; Schöne et al., 2020). Consequently, users feel actually present and involved into the VE: Being able to manipulate their surroundings, but also to be the subject to the virtual events and actions significantly increases the VE's personal and emotional relevance (Slater and Wilbur, 1997; Kisker et al., 2020; Schöne et al., 2019; Schöne et al., 2020). Over the last couple of years, it has repeatedly been demonstrated that well-designed VEs are capable of eliciting strong emotional responses (e.g., Diemer et al., 2015; Felnhofer et al., 2015; for review see; Bernardo et al., 2020), that even keep up with their real-life counterparts (Higuera-Trujillo et al., 2017; Chirico and Gaggioli, 2019). For example, the exposure to great virtual heights evokes fear responses consistently across various setups as assessed by self-reports, psychophysiological and behavioral responses (Kisker et al., 2019a; Biedermann et al., 2017; Gromer et al., 2018, 2019; Wolf et al., 2020; Asjat et al., 2018). Accordingly, VR has gained great interest as an instrument for fear paradigms. For instance, being submersed into a virtual park at night and seeing distant shadowy silhouettes effectively elicited unease and anxiety in participants (Felnhofer et al., 2015). Thus, VR setups are markedly superior to the use of conventional stimuli, e.g., static pictures, regarding emotion induction and emotional involvement (Gorini et al., 2010).

But even more, a strong sensation of presence and a high degree of immersion increase the chances that participants behave as they would in real-life situations (Blascovich et al., 2002; Slater, 2009; Kisker et al., 2019a). For example, participants effectively adapt their behavior to the environmental conditions by making smaller, slower steps when crossing a beam at a considerable height (e.g., Biedermann et al., 2017; Kisker et al., 2019a). In a similar vein, VR exposure therapies effectively trigger fear responses and modify phobia-related reactions permanently, e.g., concerning acrophobia (e.g., Coelho et al., 2009), arachnophobia (e.g., Bouchard et al., 2006), agoraphobia, and social phobia (e.g., Wechsler et al., 2019). Hence, VR bears the potential not only to elicit real-life processes within a simulation but beyond that, to transfer virtual experiences to everyday life.

Consequently, when exposed to highly emotional and interactive VR scenarios, participants' responses go far beyond self-reports or pressing keys. The use of VR setups enables participants to respond within a much wider behavioral spectrum and most importantly, to react naturally and instantly to stimuli within a fully controllable setup (e.g., Slater, 2009; Bohil et al., 2011; Kisker et al., 2019a). Initial studies elicited fear using highly interactive setups and distinct fear cues. For example, VR horror games such as "The Brookhaven Experiment" Phosphor Games (2016) trigger anxiety by contextual features, such as darkness (e.g., Felnhofer et al., 2015), but beyond that, elicit fear responses to specific stimuli, e.g., zombies approaching the protagonist (e.g., Lin, 2017). Being virtually present and involved in dangerous situations positively correlates with increases in psychophysiological measures of stress, like heart rate (e.g., Higuera-Trujillo et al., 2017; Parsons et al., 2013; Gorini et al., 2010; Kisker et al., 2019a), verbal expressions of fear like screaming, and behavioral coping reactions like dodging or closing the eyes (Lin, 2017). A correspondingly high degree of interactivity allows for the impression of actively manipulating the events, as well as being directly affected by them, and thus facilitates authentic, multidimensional fear responses (Slater, 2009; Lynch and Martins, 2015; Lin, 2017). Whereas conventional laboratory setups have to rely on rather limited or substitutional response options, highly interactive VEs allow for physical movements and full-body responses. Consequently, participants might even fight or flee from fear cues, thus physically approaching or avoiding dangers in order to cope with them.

Markers of those behaviors are electrophysiological correlates of approach and avoidance. While event-related potentials associated with approach and avoidance, like modulations of the late positive potential (e.g., Bamford et al., 2015), reflect fine-grained but only specific parts of the electrophysiological response, oscillatory neuronal dynamics allow for an ongoing assessment of cognitive processes (Bastiaansen et al., 2011). In particular, frontal alpha asymmetries (FAA) have been regarded as a canonical oscillatory correlate of emotional and motivational directions (e.g., Davidson et al., 1990; Coan et al., 2006; Rodrigues et al., 2018; Lacey et al., 2020). According to the valence model of FAA, relatively greater left frontal cortical activity relates to positive emotions and approach, whereas relatively greater right frontal cortical activity relates to negative emotion and withdrawal (Davidson et al., 1990; Davidson, 1998). Later models suggest the corresponding FAAs be indicative rather of the motivational direction, i.e., approach motivation and withdrawal motivation, independent of emotional valence (e.g., Gable and Harmon-Jones, 2008; Harmon-Jones et al., 2010; Harmon-Jones and Gable, 2018). For example, anger, obviously of negative valence, is related to relatively greater left frontal activity (e.g., Gable and Harmon-Jones, 2008). Notably, so far none of these models has emerged as being universally valid. An increasing number of studies offer divergent results and interpretations, adding to the debate about FAAs as indicators of either emotional or motivational directions (for review see e.g., Harmon-Jones and Gable, 2018). Recent models even suggest that FAAs indicate effortful control of emotions rather than emotional directions (Lacey et al., 2020; see also Schöne et al., 2015).

However, the vast majority of studies relating approach and avoidance to FAAs are based upon highly controlled laboratory setups, resembling real-life situations only to a very limited degree. Initial approaches to enhance FAA's generalizability to realistic conditions employed somewhat more immersive, so-called desktop-VR setups (Brouwer et al., 2011; Rodrigues et al., 2018). In particular, Rodrigues et al. (2018) associated active behavior with FAAs as indicated by the motivational direction model: Participants moved *via* joystick through a virtual maze depicted on a conventional desktop, encountering either a sheep, a monster, or a neutral person. Greater left frontal activation was associated with approach behavior and greater right frontal activation with withdrawal behavior respectively (Rodrigues et al., 2018). However, desktop-VR cannot offer as many degrees of freedom as highly immersive VR systems (e.g., HMDs, CAVE), inter alia, stereoscopic 360° view, and physical movements within a VE (e.g., Smith, 2019). This further enables mobile and multi-modal brain/body imaging utilizing head-tracking, motion capture or analysis via video, opening up possibilities for less restricted behavioral reactions to be explicitly recorded, analyzed, and integrated into the research design (Makeig et al., 2009).

Our previous study on FAA in virtual environments has demonstrated the general technical feasibility of combined VR EEG-FAA measurements (Schöne et al., 2021; see also Lange and Osinsky, 2020 for mobile EEG). Most importantly, the study provided the first evidence that the same stimulus material presented in VR compared to a 2D condition yields different motivational patterns reflected in the FAA data. Although the immersive nature of VR provides a more realistic environment compared to a conventional laboratory setting, a key element of the everyday experience is not yet part of the equation: Motivational tendencies, as reflected by FAA, are accompanied by a corresponding behavior adapted to the situation in which it occurs. Whereas in laboratory settings, approach or withdrawal motivation is indicated by keystroke (e.g., Gable and Harmon-Jones, 2008), the advantage of VR as a tool is the creation of controlled environments in which the participant can roam and respond freely. Consequently, the question remains whether FAAs would follow the same trend as proposed by Rodrigues et al. (2018) under highly immersive conditions that allow for physical, realistic approach and avoidance behavior.

Going beyond previous VR studies on fear, the aim is not only to capture affective fear responses by means of subjective reports elicited by the VR environment, but to examine holistic fear responses, comprising full-body behavioral expressions of fear, and to put to the test whether corresponding electrophysiological correlates of approach and avoidance behavior obtained under conventional laboratory conditions apply to highly immersive VR setups. To this end, we set up an EEG-VR study in which participants explored either a neutral or a negative, i.e., frightful cave. We aimed to situate participants in an immersive environment triggering a strong, authentic fear response. As a neutral control, a second group of participants explored a non-emotional cave. To enhance the feeling of being present in the VE, and thereby impression of being personally and physically affected by the environment and events, we build an exact, spatially aligned, physical replica of the cave - touching the cave's stone wall in the virtual world thus led to a corresponding physical sensation (see Kisker et al., 2019a; Biedermann et al., 2017). As interactivity is a major factor enhancing fear in VR setups (Lynch and Martins, 2015; Madsen, 2016; Lin et al., 2018), participants physically walked through the cave holding a controller appearing as a flashlight in VR. Thus, their virtual movements corresponded to their physical movements. Above all, they gained the impression of being able to touch their surroundings and, more importantly, of being touched by them in return.

## Affective Response

Due to VR's immersive character and based on previous findings (e.g., Lin, 2017; Felnhofer et al., 2015), we expected participants of the *negative* condition to report greater negative affect, acute fear, and presence compared to the *neutral* group (e.g., Felnhofer et al., 2015; Kisker et al., 2019a; Diemer et al., 2015).

## Behavioral Response

Going beyond the frequently investigated affective response, we hypothesized that participants would adapt their behavior to their environmental conditions. Specifically, the *negative* condition is supposed to elicit complex fear behavior, i.e., in terms of the fight-or-flight response. The cave was designed in such a way that when participants encountered the werewolf, we expected them to exhibit either one of two behaviors: Firstly, advance toward the werewolf risking physical encounter to get past it. Secondly, to retreat to safe distance and wait to see how the situation develops to plot a safe escape route. As fearful, cautious behavior is associated with slower walking compared to harmless situations (Biedermann et al., 2017; Kisker et al., 2019a), the *negative* condition might exhibit longer exploration times compared to the *neutral* condition.

## Psychophysiological Response

In line with the expected affective and behavioral responses, we assumed corresponding psychophysiological responses, i.e., decreases in heart rate variability (HRV; see e.g., Castaldo et al., 2015) to indicate increased stress levels in the *negative* condition. In contrast, we assumed that the *neutral* group would not exhibit any fear-related behavioral responses and stay unaffected in respective psychophysiological responses.

## Electrophysiological Response

Derived from the aforementioned theoretical models on frontal alpha asymmetry, we hypothesized that the FAAs would significantly differ between conditions as a function of the exhibited behavioral responses. In particular, we expected avoidance behavior to be linked to relatively greater right cortical activity, and approach behavior to relatively greater left cortical activity.

# METHODS

## Participants

The study was approved by the local ethics committee of Osnabrück University. Ninety-six participants were recruited from the local student population, gave their informed written consent, but were blind to the research question and experimental conditions. They were screened for psychological and neurological disorders using a standard screening for mental disorders and distress (anamnesis). All had a normal or corrected-to-normal vision. When vision correction was necessary, only participants wearing contact lenses could participate, not those wearing glasses. The participants were randomly assigned to one of two conditions (*negative* vs. *neutral*; see below) and blind to which condition they would participate in. As stated in the hypothesis, the cave was designed in such a way that we expected two behavioral patterns to emerge within the *negative* condition. Based on this assumption, twice as many participants were assigned to the *negative* condition as to the *neutral* condition.

The sample size was determined based on previous studies that conducted EEG measurements in a VR condition (Kisker et al., 2020; Lange and Osinsky, 2020; Schöne et al., 2021). Based on these studies, we aimed for a sample of about 25 participants per subgroup (see *Exploration time and behavior*). Although data acquisition was stopped due to the COVID-19 pandemic, we are optimistic that we obtained an adequate number of data sets corresponding to groups sizes implemented in previous VR studies (see Schöne et al., 2019; Kisker et al., 2020; Lange and Osinsky, 2020; Schöne et al., 2021). The participants received either partial course credits or 15€ for participation.

One participant was excluded during anamnesis and five participants of the *negative* condition terminated the experiment during the virtual simulation. Nine participants were excluded from analysis due to insufficient EEG data quality ($n$ = 1) or technical problems during the virtual experience ($n$ = 8). Hence, a final sample size of $N$ = 81 participants was obtained for analysis (negative: $n$ = 54, $M_{age}$ = 21.67, $SD_{age}$ = 3.57; 81.5% female, none diverse, 13% left-handed; neutral: $n$ = 27, $M_{age}$ = 23.15, $SD_{age}$ = 2.98; 59.3% female, none diverse, none left-handed). The high proportion of female participants results from a random sample with the majority of local psychology students being female. Although women are more likely to suffer from anxiety disorders and experience fear more frequently in their lives than men (e.g., McLean and Anderson, 2009), we found no significant differences between groups concerning general anxiety and current state of mind before the cave exploration. Hence, we assume that the gender imbalance did not affect the results obtained from group comparisons (see results).

## Experimental Conditions and Setup

The experiment was comprised of two experimental conditions (*negative* vs. *neutral*). For both conditions, a mixed-reality design was implemented. A VR cave was designed in Unity 5 (version 2018.3.0f2, Unity Technologies, San Francisco, United States) and a physical replica of the cave was set up in the laboratory. The physical setup resembled the virtual layout and walls, allowing for haptic sensations when touching the virtual surroundings. Relevant objects within the cave were physically represented: Ivy vines at the cave's exit were mimicked by jute ropes, a corpse was mimicked by a life-size puppet, tree trunks and rocks by paper-mâché replicas (**Figure 1**). The cave's layout and the path running through it were identical for both conditions. There was only one possible path through the cave. The virtual environment was presented with a wireless version of the HTC Vive Pro (HTC, Taoyuan, Taiwan) head-mounted display (HMD). Movement within the cave was implemented through active, physical walking. All participants held a Vive controller in their dominant hand, serving as a flashlight.

The difference between the caves was achieved by atmospheric elements alone as outlined in detail below. Events related to the atmospheric elements, e.g., the onset of wind howling, were automatically triggered depending on the position of the participant within virtual the cave. Each event was triggered only once per participant. Exemplary videos of the scenery and a video abstract are provided (see availability of data, material, and code).

### Exploration of the Negative Cave

The *negative* condition was designed as a gloomy environment. The cave was only dimly illuminated. A mutilated corpse, the sound of crying, and a werewolf were used as fear-triggering stimuli (**Figure 1B1,D1**). In the cave's entrance area, it was obvious that a frightening environment was to be expected, with weapons and corpses laying on the floor at distance (**Figure 1C1**). The area

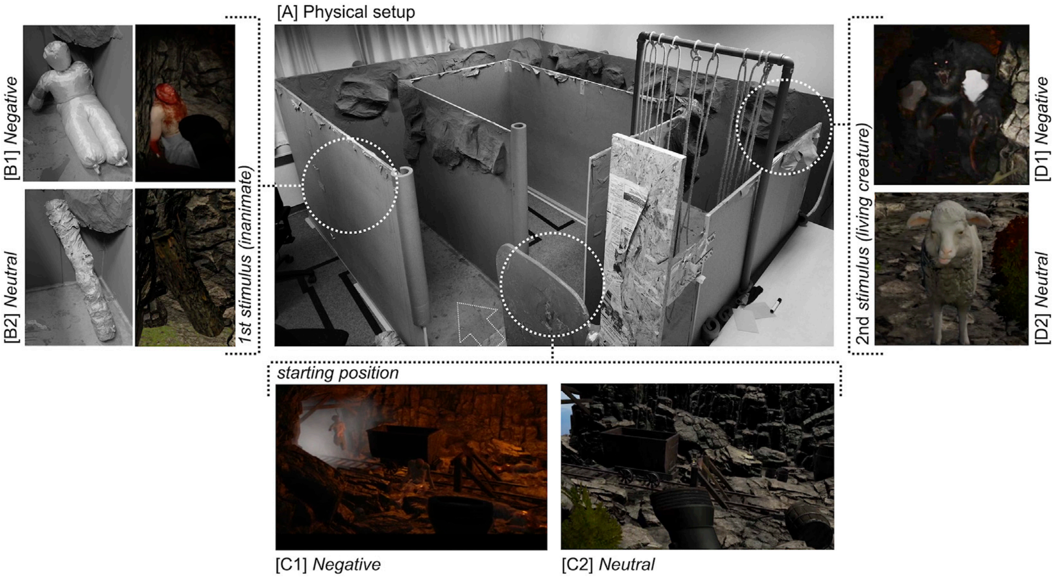


**FIGURE 1 |** Illustration of the (physical) cave and respective stimuli per condition. Panel **(A)** depicts the physical replica of the cave which participants walked through. The dotted white arrow indicates the initial direction in which the participants moved through the cave. The position of relevant creatures/objects in their virtual and physical form (see panels **(B)** and **(D)**) are indicated respectively.The cave's entrance area (panel **C**) served as an indicator of what environment was to be expected. It gave participants an immediate chance to terminate the experiment.

aimed to allow the participants to immediately terminate the experiment if they did not dare to explore the negative, i.e., frightful cave. To navigate through the cave, participants had to turn around 180°. At a distance of about 2 m lay a mutilated corpse at the first turn-off of the path (**Figure 1B1**). Shortly before reaching the corpse, crying could be heard. The participants had to step around the corpse to follow the path any further. Shortly before they reached the next turn-off, a monstrous roar and footsteps could be heard. Once they had passed this turn-off, a 2 m high werewolf was visible, walking towards the participants from the other end of the cave up to a fixed point at the third turn-off of the cave (**Figure 1D1**). Participants did not know that the werewolf would not approach them any further than to this fixed point. The werewolf stopped at the junction, leaving room to pass it, still roaring and striking towards the participants. Participants had to walk towards the werewolf and turn off directly in front of it to reach the cave's exit (**Figure 2**).

### Exploration of the Neutral Cave

The *neutral* condition was designed as a non-emotional environment. The cave was also only dimly illuminated, but brighter than the negative cave. All stimuli of the *negative* condition were replaced by neutral stimuli. In detail, the corpse was replaced by a tree trunk, the werewolf by a sheep (**Figure 1B2,D2**), and wind howling replaced the sound of crying (**Figure 2**). The entrance area of the cave was designed plainly. Wooden barrels and buckets lay in the places where the *negative* condition contained weapons and corpses (**Figure 1**, C2). To navigate through the cave, participants had to turn around 180°. At the first turn-off of the path lay a tree trunk (**Figure 1B2**). Shortly before reaching the tree trunk, wind howling could be heard. Shortly before the second turn-off, a bleating sheep and its footsteps could be heard. Stepping around this turn-off, a sheep became visible, walking towards the participant from the other end of the cave up to a fixed point at the third turn-off of the cave (**Figure 1D2**). Participants did not know that the sheep would not approach them any further than to this fixed point. The sheep stopped at the junction, leaving room to pass it, still bleating and eating grass. Participants had to walk towards the sheep and turn off directly in front of it to reach the cave's exit (**Figure 2**).

## Procedure

Participants were blind to the experimental conditions and design but were informed that the cave might be perceived as unpleasant. During experiment preliminaries, it was checked whether participants had gained any previous information about the experiment's research objective, content, or design. If any of this was true, they were excluded from the experiment. Participants were screened for psychological and neurological disorders using a standard screening for mental disorders. Special attention was paid to anxiety disorders, subclinical fears, and current emotional strain. If participants were currently experiencing neurological or psychological disorders or were currently undergoing psychological, psychiatric, or neurological treatment, they were excluded from participation in the study.

Participants were asked to fill out a set of questionnaires, including the German versions of the *State-Trait-Anxiety-Inventory, trait scale* (*STAI-T*; Laux et al., 1981), the *Sensation Seeking Scale Form-V* (*SSS-V*; Zuckerman, 1996), the *E-Scale* (Leibetseder et al., 2007), the BIS/BAS scale (Carver and White, 1994; Strobel et al., 2001), *the reinforcement sensitivity theory personality questionnaire* (RST-PQ; Corr and Cooper,

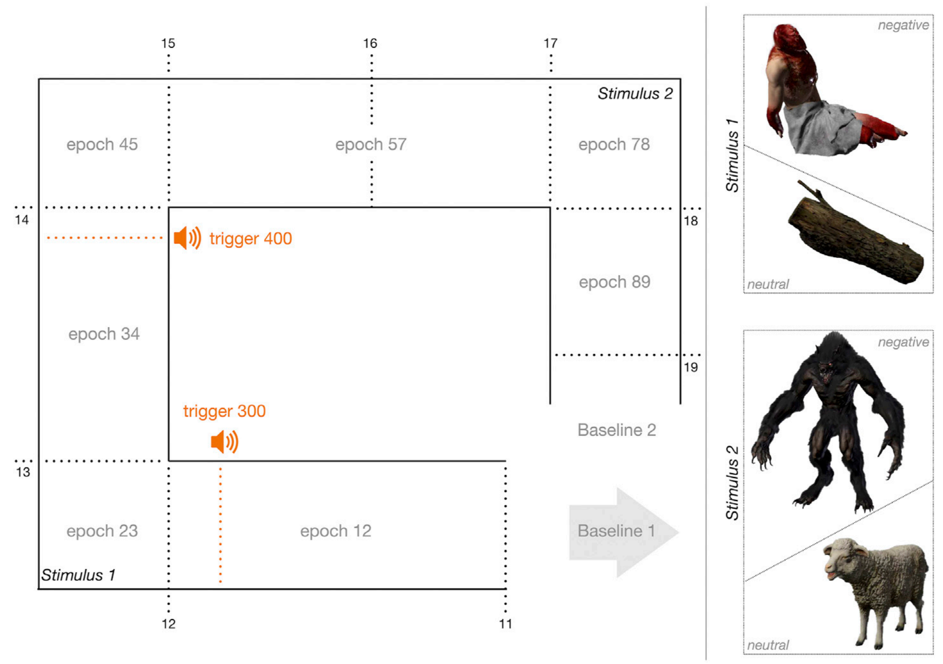


**FIGURE 2 |** Schematic layout of the virtual cave and exploration epochs. The gray arrow indicates the initial position and the gaze direction for all participants. The positions of relevant objects (see stimuli 1 and 2) are indicated respectively. Dotted lines mark the positions and triggers sent to EEG. The sections of the route through the cave are marked as epochs. For example, epoch 12 denotes the section between triggers 11 and 12. Prominent event within the cave are marked respectively. Epoch 12: Walking towards the corpse/tree trunk and sound of crying/wind howling; epoch 34: Walking away from the corpse/tree trunk and sound of roaring/bleating; epoch 57: Walking towards the werewolf/sheep; Trigger 300: Crying/wind sounds; Trigger 400: Roaring/bleating.

2016) and *revised paranormal belief scale* (RPBS; Tobacyk, 2004). Afterward they were equipped with a wireless mobile EEG system and ECG electrodes (see electrophysiological recordings). For the assessment of their current mood, participants filled out the German version of the *Positive and Negative Affect Schedule* (*PANAS*; Krohne et al., 1996) immediately before instructions.

Participants were instructed that their task would be to explore a cave and find its exit, leading into a village. They got no information concerning the cave's layout or size in advance. They received no prior information about the cave's affective design and stimuli, like sheep, werewolf, or corpse. If they were unable to find the exit or did not want to proceed with exploring the cave, they were free to return to their starting position or terminate the experiment. They were instructed how to use the controller as a flashlight and to move physically through the cave. All participants were instructed to immediately terminate the experiment if they felt too uncomfortable (both physically or mentally).

Participants were equipped with a wireless version of the *Vive Pro* HMD before entering the VR laboratory and did not see the physical setup of the cave at any time before the virtual experience started. To increase the participants' immersion and maintain it during the experiment, any communication with the investigators was stopped completely from the moment they entered the experimental room. Participants were informed that the investigators would not communicate with them or respond to any speech as long as they were in the cave unless they gave a predetermined command to terminate the experiment.

An ECG baseline measurement was recorded in a plain default VR room with the HMD turned on. Afterward the cave simulation was launched. Participants were free to start exploring the cave as soon as they felt comfortable doing so. When they left the cave through the exit, they entered a safe, pleasant-looking fishing village. Once participants reached the village, they stood still for 30 s, allowing for another baseline measurement. Afterward they were distinctly addressed by the investigator and informed that the equipment would be removed from them. They immediately left the VR laboratory. If participants terminated the experiment at an early stage, the environment was immediately switched to the safe fishing village to release the participants from the unpleasant environment as quickly as possible.

To assess mood and the sense of presence, participants were asked to filled out the *PANAS*, the *Igroup Presence Questionnaire* (*IPQ*; Schubert et al., 2001), and an in-house post-questionnaire asking about the emotional and motivational experiences in the cave. The latter included a visual analog scale (VAS) to determine the physical distance to either the werewolf or the sheep which participants preferred (zero up to 10 m). Before participants left the laboratory, they were rewarded with either partial course credits or 15€. The principal psychological investigators ensured that the participants felt safe and sound after the experiment.

## Pre-Processing

### Electrophysiological Recording and Pre-processing

For EEG-data acquisition, the mobile EEG-system LiveAmp32 by Brain Products (Gilching, Germany) was used. The electrodes were applied in accordance with the international 10–20 system. An online reference (FCz) and ground electrode (AFz) were included. The impedance of all electrodes was kept below 15 kΩ. The data was recorded with a sampling rate of 500 Hz and online band-pass filtered at 0.016–250 Hz. Triggers marking the position of the participant within the cave and the onset of virtual events (e.g., wind howling, monstrous roar, etc.; see **Figure 2**) were transmitted from Unity to Lab Streaming Layer (LSL by SCCN, https://github.com/sccn/labstreaminglayer), which was used to synchronize the EEG data stream and Unity triggers.

All pre-processing steps serve the function of ensuring robust data quality and comparability. In particular, the aim is to reduce the amount of variance caused by common EEG artifacts (e.g., due to eye blinks). The EEG data was analyzed using MATLAB (version R2020b, MathWorks Inc) and EEGLAB (Delorme and Makeig, 2004). The continuous EEG data was bandpass-filtered between 1Hz, reducing slow drifts, and 30 Hz to remove high-frequency artifacts like electrical line noise (see Cohen, 2014). The average reference was used for further offline analysis as recommended for large sets of electrodes (see Cohen, 2014). Artifact correction was performed using "Fully Automated Statistical Thresholding for EEG artifact Reduction" (*FASTER*; Nolan, Whelan and Reilly, 2010). In brief, this procedure automatically detects and removes artifacts, like blinks and white noise, based upon statistical estimates for various aspects of the data, e.g., channel variance. *FASTER* has high sensitivity and specificity for the detection of various artifacts and is described in more detail elsewhere (e.g., Nolan et al., 2010). Due to recommendations for the use of *FASTER* with 32 channel setups, independent component analysis (ICA) and channel interpolation were applied, whereas channel rejection and epoch interpolation were not applied. Each electrode was detrended separately to ensure the same statistical properties for the time series (Cohen, 2014) before segmenting the data into epochs based upon the position triggers. The segmentation of the continuous EEG data into epochs matching the cave sections enabled a more differentiated analysis of the cave exploration. Per epoch, a windowed fast Fourier transform (FFT) was calculated to isolate alpha-band-specific activity (8–13Hz; Berger, 1929). To this end, a hamming window with a length of one second and 50% overlap was applied. The mean FFT score was logarithmized to calculate alpha-band power. For the calculation of the FAA score, the electrode F4 was subtracted from the electrode F3 [logarithmized left alpha power minus logarithmized right alpha power; $\ln(\mu V^2)$]. The former steps to calculate FAAs follow the standard procedure recommended by (Smith et al., 2017).

### Exploration time and Behavior

Exploration time was measured in seconds from the initial entrance into the cave (marker 11, **Figure 2**) to exiting the cave (marker 19, **Figure 2**) and for the path section along which participants headed directly towards the werewolf/the sheep (epoch 57).

As expected, the examination of the video recordings of the cave exploration revealed two different behavioral patterns manifested within the *negative* condition, subdividing the *negative* group into two subgroups: When first encountering the werewolf, participants of the *negative* group either retreated, i.e., hesitated or hid behind a former wall (subgroup labeled "*hesitating*"), or quickly advanced toward the werewolf to get past it, hastening around the cave's next turn-off (subgroup labeled "*hastening*"). They were assigned to the subgroups by the assessment of three investigators. To cross-check the division into the three subgroups, we implemented a video rating of the participants' fear behavior by blind raters (see **Box 1**). Since the blind ratings favored the classification of the subgroups (see **Box 1**), the investigators' proposed subdivision was adopted (*hesitating* group: $n = 33$, $M_{\text{age}} = 21.70$, $SD_{\text{age}} = 3.85$, 87.9% female, 87.9 right-handed; *hastening* group: $n = 21$, $M_{\text{age}} = 21.62$, $SD_{\text{age}} = 3.17$, 71.4% female, 85.7% right-handed; *neutral* group: $n = 27$, $M_{\text{age}} = 23.15$, $SD_{\text{age}} = 2.98$, 59.3% female, all right-handed). We provided an analysis of both conditions (*negative* versus *neutral*) without subdivisions into the *hastening* group and the *hesitating* group as supplementary material (see **Supplementary Material S1**).

### Cardiovascular Measurements and Pre-processing

A three-channel ECG (Brain Products, Gilching, Germany) was applied and transmitted to the mobile EEG system. Electrodes were placed at the left collarbone, the right collarbone, and at the lowest left costal arch. The ECG was recorded synchronously with the EEG data.

The ECG data was segmented into the baseline measurements before the start of the cave exploration (60 s) and directly after leaving the cave, i.e., standing in the village (30 s). ECG measures during cave exploration were not further analyzed due to insufficient data quality. Participants who were excluded due to technical problems or insufficient EEG data quality and those who terminated the experiment early were excluded from ECG analysis. The datasets were further preprocessed using BrainVision Analyzer 2.2.0 (Brain Products, Gilching, Germany). Datasets were filtered between 5 and 45 Hz to remove low and high-frequency artifacts. Additionally, a notch filter (50 Hz) was applied. An automatic R-peak detection was applied and visually counterchecked. 14 datasets were excluded due to insufficient ECG quality during at least one of both baselines. For the remaining 67 datasets ($n_{\text{hesitating}} = 29$; $n_{\text{hastening}} = 18$; $n_{\text{neutral}} = 20$), the classical HRV parameter, i.e., the root mean square of successive differences (rmSSD) was calculated per baseline using MATLAB. The parameter rmSSD was chosen for analysis as it is recommended for ultra-short-time measurements (10—60 s; Shaffer and Ginsberg, 2017). The individual change in rmSSD between both baselines was calculated per participant and averaged per group for comparisons (delta = baseline 2—baseline 1; see **Figure 2**).

**BOX 1 | Cross-check of group subdivision by blind rating**

**Procedure:** A blind video rating was conducted to check the subdivision into the subgroups *hesitating*, *hastening,* and *neutral* based on three investigators' assessment. To this end, recordings of the participants exploring the cave were used. The recordings did neither reveal the participants' identity, nor in which experimental condition they were, nor what they saw in the virtual environment. Only their behavior within the physical replica was visible. Videos of participants who terminated the experiment ($n = 5$) or did not agree to the use and publication of the recordings ($n = 4$) were not included in the rating. The naive raters' task was to evaluate to what extent the person in the video showed fear in their behavior. To do so, they were asked to rate the person's fear on a scale from zero (*no fear at all*) to six (*very strong fear*). Each rater evaluated each of the videos ($n = 77$) in randomized order. They were allowed to take breaks if needed.

**Blind raters:** Twenty-seven blind raters completed the video rating. It was ensured that none of the raters had prior knowledge of the original study, that none participated in the original study, and that none suffered from any psychological or neurological conditions. Four raters were excluded due to the anamnesis' exclusion criteria, resulting in $n = 23$ valid ratings ($M_{age} = 21.74$, $SD_{age} = 2.54$, 20 female, 3 male, none diverse). To ensure the raters' aptitude, their empathic ability and emotional competence were assessed using the German versions of the e-scale (Leibetseder et al., 2007), and the self-assessment of emotional intelligence (SEK-27; Berking and Znoj, 2008). They were blind to the content, experimental conditions, and objectives of the original study.

**Statistical analysis:** Per rater, mean fear scores were calculated. For this purpose, the individual video ratings were averaged based on conditions (*negative* vs. *neutral*), as well as based on the previous division of subjects into subgroups (*hesitating* vs. *hastening* vs. *neutral*). These mean fear scores were tested for normal distribution using the Shapiro-Wilk test and further analyzed using separate *t*-tests for dependent samples.

**Results:** Raters were of average empathic ability ($M = 97.10$) and emotional intelligence ($M = 80.74$). All mean fear scores were normally distributed (all $Ws(23) > 0.90$; all $ps > .10$). *T*-tests revealed significantly different fear scores for both conditions and all subgroups (all $ts(22) > |5.15|$, all $ps < .001$). In particular, fear was rated to be more pronounced in the negative condition compared to the neutral condition (negative condition: $M = 2.81$, $SD = 0.77$; neutral condition: $M = 1.15$, $SD = 0.54$), and most importantly, most pronounced in the *hesitating* subgroup, with the *hastening* subgroup showing more pronounced fear than the *neutral* subgroup (hesitating: $M = 3.56$, $SD = 0.54$; hastening: $M = 1.53$, $SD = 0.66$; neutral: $M = 1.15$, $SD = 0.54$).

**Conclusion**: The blind ratings are in line with the subdivision into the subgroups *hesitating*, *hastening*, and *neutral*, as proposed based on the investigators' assessment. All subgroups differed significantly in the fear levels as assessed by naive raters based on the participants' behavior. Consequently, participants' fear levels were explicitly and distinctly expressed in their behavior, even observable by blind, naive raters, indicating a high level of realistic fear behavior.

## Statistical Analysis

All statistical analyses were carried out using SPSS 26 (IBM). All variables were tested for normal distribution regarding each group separately using the Shapiro-Wilk test and all further statistical tests were chosen accordingly (see **Supplementary Material S2** for a detailed report of the Shapiro-Wilk test). In case that at least one subgroup per variable or at least one subscale or subvariable of a measure was not normally distributed ($p < 0.1$), a non-parametric test (Kruskal-Wallis test, Mann-Whitney *U*-test) was used for the analysis of that measure, as parametric tests, i.e., ANOVA and *t*-test are less robust to violation of normal distribution in case of unequal group sizes.

### Subjective Measures

The scales of the questionnaires were calculated as the sum of the corresponding item values (sum scale). Concerning the PANAS, in addition to the scores for positive and negative affect, the change in affect was calculated as the difference between pre-measurement and post-measurement (change = post–pre). For the in-house post-questionnaire, the subscales *affect* and *motivation* were calculated as mean values of the corresponding items. The preferred physical distance to either the werewolf or the sheep (*via* VAS) was transformed into the distance in percent (relative distance = preferred distance/total distance possible).

All questionnaires were analyzed using the Kruskal-Wallis test and complemented by post-hoc Mann-Whitney *U*-tests, with exception of the SSS-V, which was analyzed using a one-way ANOVA, complemented by post-hoc *t*-tests. Due to the directional wording of the hypothesis concerning acute fear and presence, negative affect, motivation, and presence were tested one-tailed. All other self-reports were tested two-tailed. Cronbach's *alpha* was calculated per scale and reached at least acceptable levels for most scales ($\alpha \geq 0.70$) with exception of the following subscales: BIS/BAS: goal drive, fun seeking, reward responsiveness; RST-PQ: reward interest, impulsivity; IPQ: Spatial presence, realness ($0.45 < \alpha < 0.70$, see **Supplementary Material S3** for details).

### Dependent Measures

#### *Exploration Time*

Exploration time was compared between groups using the Kruskal-Wallis test, followed by post-hoc Mann-Whitney *U*-tests. Due to the directed hypothesis concerning exploration time, the total exploration time and the exploration time during epoch 57 (see **Figure 2**) were tested one-tailed.

#### *Electroencephalic Measures*

For statistical analysis of the FAAs, individual outliers were determined per epoch. Scores with a greater interquartile distance than 1.5 from the group mean were excluded from the analysis of the individual epoch. The FAA scores were analyzed based upon the subdivision of the *negative* condition into the subgroups "*hesitating*" and "*hastening*" and the *neutral* condition. The latter was not further subdivided (see results). The Kruskal-Wallis test was used for analysis and complemented by post-hoc Mann-Whitney *U*-tests. The parameter $r$ ($\sqrt{\eta^2}$) was calculated as an estimate of effect size.

#### *Cardiovascular Measures*

The average change in rmSSD as a measure of HRV (delta = baseline 2—baseline 1) was compared between groups using the Kruskal-Wallis test and post-hoc Mann-Whitney *U*-tests. The parameter $r$ ($\sqrt{\eta^2}$) was calculated as an estimate of effect size. Due to the directed hypothesis concerning HRV, the measure was tested one-tailed.

**TABLE 1 |** Test statistics for Mann-Whitney U-test regarding the subjective reports.

| | | Descriptive statistics | | | *Mann-Whitney U*-test | | | |
|---|---|---|---|---|---|---|---|---|
| | | ***n*** | ***Md*** | ***SD*** | ***U*** | ***Z*** | ***P*** | ***effect size r*** |
| RST-PQ: Impulsivity | Hesitating | 33 | 17.00 | 3.52 | 225.00 | −2.169 | 0.030* | 0.17[a] |
| | Hastening | 21 | 19.00 | 2.79 | | | | |
| | Hesitating | 33 | 17.00 | 3.52 | 308.50 | −2.044 | 0.041* | 0.26[a] |
| | Neutral | 27 | 19.00 | 4.16 | | | | |
| | Hastening | 21 | 19.00 | 2.79 | 280.50 | −0.063 | 0.95 | 0.01 |
| | Neutral | 27 | 19.00 | 4.16 | | | | |
| RST-PQ: Fight-Flight-Freeze-System | Hesitating | 33 | 25.00 | 4.80 | 255.00 | −1.627 | 0.104 | 0.22[a] |
| | Hastening | 21 | 21.00 | 5.98 | | | | |
| | Hesitating | 33 | 25.00 | 4.80 | 278.50 | −2.49 | 0.013* | 0.32[b] |
| | Neutral | 27 | 22.00 | 5.30 | | | | |
| | Hastening | 21 | 21.00 | 5.98 | 264.00 | −0.406 | 0.684 | 0.06 |
| | Neutral | 27 | 22.00 | 5.30 | | | | |
| PANAS negative affect T2[1] | Hesitating | 33 | 14.00 | 5.17 | 290.50 | −0.728 | 0.240[1] | 0.10[a] |
| | Hastening | 20 | 14.50 | 5.43 | | | | |
| | Hesitating | 33 | 14.00 | 5.17 | 197.50 | −3.406 | 0.001***[1] | 0.45[a] |
| | Neutral | 24 | 11.00 | 1.80 | | | | |
| | Hastening | 20 | 14.50 | 5.43 | 155.00 | −2.225 | 0.013*[1] | 0.34[a] |
| | Neutral | 24 | 11.00 | 1.80 | | | | |
| Change in negative affect[1] | Hesitating | 32 | 2.00 | 4.89 | 275.50 | −0.840 | 0.205[1] | 0.11[a] |
| | Hastening | 24 | 1.50 | 4.74 | | | | |
| | Hesitating | 32 | 2.00 | 4.89 | 189.00 | −3.244 | 0.001***[1] | 0.43[a] |
| | Neutral | 24 | −1.00 | 2.47 | | | | |
| | Hastening | 24 | 1.50 | 4.74 | 141.00 | −2.359 | 0.009*[1] | 0.34[a] |
| | Neutral | 24 | −1.00 | 2.47 | | | | |
| Change in positive affect | Hesitating | 32 | 4.50 | 5.86 | 273.500 | −0.596 | 0.551 | 0.08 |
| | Hastening | 24 | 3.00 | 4.39 | | | | |
| | Hesitating | 32 | 4.50 | 5.86 | 245.50 | −2.299 | 0.021* | 0.31[a] |
| | Neutral | 24 | 1.00 | 4.62 | | | | |
| | Hastening | 24 | 3.00 | 4.39 | 152.00 | −1.868 | 0.062 | 0.27[a] |
| | Neutral | 24 | 1.00 | 4.62 | | | | |
| In-house: affect[1] | Hesitating | 33 | 3.71 | 1.60 | 273.00 | −1.306 | 0.096[1] | 0.20[a] |
| | Hastening | 21 | 4.00 | 1.83 | | | | |
| | Hesitating | 33 | 3.71 | 1.60 | 34.50 | −6.113 | <0.001***[1] | 0.78[b] |
| | Neutral | 27 | 7.29 | 1.31 | | | | |
| | Hastening | 21 | 4.00 | 1.83 | 75.00 | −4.339 | <0.001***[1] | 0.63[b] |
| | Neutral | 27 | 7.29 | 1.31 | | | | |
| In-house: motivation[1] | Hesitating | 33 | 3.25 | 1.82 | 235.00 | −1.980 | 0.024*[1] | 0.30[a] |
| | Hastening | 21 | 4.50 | 1.96 | | | | |
| | Hesitating | 33 | 3.25 | 1.82 | 95.00 | −5.22 | <0.001***[1] | 0.67[b] |
| | Neutral | 27 | 7.00 | 1.52 | | | | |
| | Hastening | 21 | 4.50 | 1.96 | 128.50 | −3.233 | 0.001***[1] | 0.47[a] |
| | Neutral | 27 | 7.00 | 1.52 | | | | |
| In-house: relative distance[1] | Hesitating | 30 | 0.74 | 0.29 | 264.5 | −0.117 | 0.454[1] | 0.02 |
| | Hastening | 18 | 0.69 | 0.21 | | | | |
| | Hesitating | 30 | 0.74 | 0.29 | 129.00 | −4.41 | <0.001***[1] | 0.58[b] |
| | Neutral | 27 | 0.22 | 0.27 | | | | |
| | Hastening | 18 | 0.69 | 0.21 | 63.00 | −4.172 | <0.001***[1] | 0.62[b] |
| | Neutral | 27 | 0.22 | 0.27 | | | | |
| IPQ: spatial presece[1] | Hesitating | 33 | 8.00 | 3.71 | 249.00 | −1.736 | 0.042[1] | 0.24[a] |
| | Hastening | 21 | 5.00 | 5.13 | | | | |
| | Hesitating | 33 | 8.00 | 3.71 | 309.00 | −2.033 | 0.021[1] | 0.26[a] |
| | Neutral | 27 | 6.00 | 6.20 | | | | |
| | Hastening | 21 | 5.00 | 5.13 | 264.50 | −0.396 | 0.346[1] | 0.06 |
| | Neutral | 27 | 6.00 | 6.20 | | | | |

Note. *The detailed statistics for Kruskal-Wallis test are provided in* ***Supplementary Material S2****. The respective descriptive statistics are given per condition. The parameter* r ($\sqrt{\eta^2}$) *was provided as an estimate of effect size (a = small effect, b = medium effect, c = large effect). Significant differences between groups were marked accordingly (**p < 0.05; **p ≤ 0.01, ***p ≤ 0.001). One-tailed tests are marked accordingly[1].*

# RESULTS

## Subjective Measures

No group differed significantly from others in personality traits that otherwise might have an impact on the perception of and reactions to the specific VR scenario, such as anxiety, empathy, paranormal belief, behavioral activation system, and behavioral inhibition system (all $Hs(2) < 5.10$, $p > 0.05$; see **Supplementary Material S2** for details), as well as sensation seeking ($F$ (2,74) = 3.05, $p = 0.053$). However, groups differed in impulsivity ($H$ (2) = 6.23, $p = 0.044$) and in the fight-flight-freeze system (FFF-S; $H$ (2) = 6.46, $p = 0.040$) as assessed by RST-PQ. In particular, the *hesitating* group scored lower in impulsivity compared to the *hastening* and *neutral* groups. Moreover, the *hesitating* group scored significantly higher in the FFF-S compared to the *neutral* group. The difference in the FFF-S between the *hesitating* and *hastening* groups followed the same trend but did not reach significance. The *hastening* and *neutral* groups did not differ significantly in both traits (see **Table 1**).

Before the cave exploration, groups did not differ concerning their mood (all $Hs(2) < 1.1$, all $ps > 0.50$). However, after the cave exploration, groups reported different levels of negative affect, as well as differing changes in negative and positive affect. In detail, both *hesitating* and *hastening* groups experienced equal negative affect as well as similar increases in negative affect, but significantly stronger increases compared to the *neutral* group (see **Table 1**). Surprisingly, the *hesitating* group reported significantly higher increases in positive affect compared to the *neutral* group as well. The *hastening* group followed the same trend but did not reach significance. The *hastening* and the *hesitating* groups experienced similar increases of positive affect (see **Table 1**). All groups reported similar levels of presence (all $Hs(2) < 5.20$, all $ps > 0.07$), with exception of the sensation of *spatial presence* ($H$ (2) = 5.17, $p = 0.038$)[1]. In particular, the *hesitating* group felt more spatially present compared to both other groups, whereas the *hastening* and the *neutral* groups exhibited similar levels of spatial presence (see **Table 1**).

As assessed by the in-house post-questionnaire, the *hastening* and the *hesitating* groups preferred a significantly greater distance to the werewolf, whereas the *neutral* group preferred a significantly closer distance to the sheep (22% of the possible distance). Descriptively, the *hesitating* group (74% of the possible distance) preferred a slightly greater distance to the werewolf compared to the *hastening* group (69% of the possible distance), but the groups did not differ significantly (see **Table 1**). Furthermore, both the *hesitating* group and the *hastening* group perceived the cave as strongly negative and reported a significantly greater motivation to leave the cave at an early stage compared to the *neutral* group. Even more, the *hesitating* group exhibited a significantly stronger motivation to leave the cave early compared to the *hastening* group. The *hastening* group perceived the cave as significantly more negative compared to the *neutral* group as well, and reported a high motivation to leave the cave early, whereas participants of the *neutral* group tended to perceive the cave as rather comfortable and were only slightly motivated to leave it at an early stage (see **Table 1**).

**TABLE 2 |** Test statistics for Kruskal-Wallis test regarding exploration time and HRV data.

| | Kruskal-wallis test | | |
|---|---|---|---|
| | ***H*** | ***Df*** | ***P*** |
| Total exploration time[1] | 14.791 | 2 | 0.001***[1] |
| Exploration time epoch 57[1] | 28.173 | 2 | <0.001***[1] |
| HRV: Delta rmSSD[1] | 2.003 | 2 | 0.184[1] |

Note. *Significant differences between groups (*p < 0.05; **p ≤ 0.01, ***p ≤ 0.001) and one-tailed tests[1] were marked accordingly.*

## Dependent Measures

### Exploration time and Behavior

The *hesitating* group took approximately 1.7 times as long as the *hastening* group and the *neutral* group to reach the cave's exit and thus to end the exploration ($Md_{hesitating.}$ = 49.7s; $Md_{hastening.}$ = 29.10, $Md_{neutral.}$ = 33.15). In contrast, the *hastening* and the *neutral* groups took approximately the same time to end the exploration (see **Tables 2**, **3**). This pattern was evident for epoch57, when participants headed towards the werewolf/ sheep, as well (see **Table 2**, exploration time epoch 57). The *hesitating* group walked significantly slower towards the werewolf compared to the *hastening* group ($U = 81.00$, $z = -4.42$, $p < .001^1$, $r = 0.62$) and the *neutral* group towards the sheep ($U = 121.00$, $z = -4.52$, $p < .001^1$, $r = 0.60$), whereas *hastening* group and *neutral* group walked at the same pace ($U = 255.00$, $z = -0.11$, $p = .456^1$, $r = 0.02$). In detail, the *hesitating* group took more than three times as long as both other groups for this path section ($Md_{\text{hesitating}} = 21.57$; $Md_{\text{hastening}} = 6.60$; $Md_{\text{neutral}} = 6.09$; $Md$ in seconds).

The significant difference in exploration time was reflected in the directly observable behavior within the cave: The *neutral* group explored the cave rather casually, maintaining a constant walking pace and showing no particular signs or verbalizations of unease. In contrast, both *negative* groups walked rather cautiously, looking around turn-offs before continuing the exploration. Both subgroups explicitly expressed fear by verbalizations and body language. For example, participants gasped, looked around nervously, or wrapped their arms protectively around themselves. Five participants terminated the experiment either at first sight of the cave's entrance area ($n = 1$) or at first sight of the werewolf ($n = 4$). Beyond that, the *hesitating* group either stopped or even hid behind the former wall when detecting the werewolf, whereas the *hastening* group did not hesitate at all, but advanced toward the werewolf to get past it (see data repository for exemplary video recordings). Based on these bodily fear cues, even naive raters were able to classify participants' fear levels adequately, indicating a high consistency with real-life fear behavior (see **Box 1**).

[1]Measures of acute fear, i.e., negative affect and motivation to leave the cave as assessed via PANAS and the in-house post-questionnaire, as well as HRV and exploration time, were tested one-tailed due to directed hypotheses. All other hypotheses are tested two-tailed.

**TABLE 3 |** Test statistics for post-hoc Mann-Whitney U-test regarding exploration time.

| | | Descriptive statistics | | | *Mann-Whitney U*-test | | | |
|---|---|---|---|---|---|---|---|---|
| | | *N* | *Md* | *SD* | *U* | *Z* | *p* | *effect size r* |
| Total exploration time[1] | Hesitating | 31 | 49.70 | 70.11 | 158.00 | −2.932 | 0.002**[1] | 0.41[b] |
| | Hastening | 20 | 29.10 | 31.14 | | | | |
| | Hesitating | 31 | 49.70 | 70.11 | 185.00 | −3.49 | <0.001***[1] | 0.46[b] |
| | Neutral | 26 | 33.15 | 22.77 | | | | |
| | Hastening | 20 | 29.10 | 31.14 | 285.00 | −0.044 | 0.483[1] | 0.01 |
| | Neutral | 26 | 33.15 | 22.77 | | | | |

Note. *The respective descriptive statistics are given per group and the effect size r ($\sqrt{\eta^2}$; a = small effect, b = medium effect) was determined. Significant differences between groups (*p < 0.05; **p ≤ 0.01, ***p ≤ 0.001) and one-tailed tests[1] were marked accordingly.*

### Cardiovascular Measures

All groups exhibited equal changes in rmSSD between both baseline measurements ($H$ (2) = 2.00, $p$ = .184[1], see **Table 2**). Descriptively, all groups exhibited an increased rmSSD in the second baseline compared to the first baseline ($Md_{\text{hesitating}}$ = 13.58; $Md_{\text{hastening}}$ = 17.74; $Md_{\text{neutral}}$ = 17.81), indicating higher stress levels during the first baseline.

### Electroencephalographic Measures

The Kruskal-Wallis test revealed differences regarding the FAA scores between the three subgroups for epoch 34 ($H$ (2) = 6.13, $p$ = 0.047) and epoch 57 ($H$ (2) = 6.59, $p$ = 0.037). However, they did not differ during baseline or further epochs (all *Hs(2)* < 4.6; all *ps* > 0.10; see **Supplementary Material S2** for details).

Hence, only epoch 34 and epoch 57 were further analyzed by post-hoc Mann-Whitney *U*-tests. In epoch 34, a significantly stronger left frontal cortical activity was observed in the *hastening* group compared to the *neutral* group, which exhibited a stronger right frontal cortical activity (see **Table 4** and **Figure 3**). However, the *hesitating* group did not differ from the *hastening* group or from the *neutral* group with respect to their FAA scores. In contrast, the *hastening* and the *hesitating* groups differed significantly during epoch 57, with the *hesitating* group showing greater left frontal cortical activity and the *hastening* group showing greater right frontal cortical activity. Both did not differ significantly from the *neutral* group during this epoch (all *Us* > 240.00, all *ps* > 0.05, see **Table 4** and **Figure 3**).

## DISCUSSION

The present study aimed to examine authentic fear responses, especially complex behavioral expressions of fear, and the electrophysiological correlates of approach and avoidance, i.e., frontal alpha asymmetries (FAA) in an immersive virtual reality setup. The incremental value of the study lies particularly in the simultaneous examination of realistic behavior and the associated electrophysiological responses. To this end, participants explored either a negative, i.e., frightful cave, containing corpses and a monstrous werewolf, or a neutral cave, containing tree trunks and a sheep. As expected, the negative cave elicited significantly stronger negative affect, fear, and the motivation to withdraw from the scenario earlier as opposed to the *neutral* condition. Going beyond previous findings, these affective responses were very pronounced and identifiably reflected in the participants' behavior. While the neutral condition's participants explored the cave rather casually, the *negative* condition's participants walked rather cautiously, adapting their pace to the threatening atmosphere. Even more, the *negative* condition exhibited two different behavior patterns, subdividing participants into a *hesitating* and a *hastening* group. Surprisingly, and even though self-reports and behavior indicated great differences in emotional experiences, the different groups could be distinguished in only two out of seven cave sections based on the FAAs.

### Affective Responses to the Virtual Cave

In line with previous research, the respective design of the cave was sufficient to trigger distinct emotional reactions as intended. Indicative of successful fear elicitation, both negative subgroups reported higher levels of acute fear compared to the *neutral* condition. Specifically, both *negative* groups reported highly negative affect, a strong fear of the respective stimuli, and great motivation to leave the cave early, while the *neutral* group did not. With all negative stimuli removed, a still dimly lit cave exhibited no particular reports of fear in the *neutral* condition. Hence, while context and distinct cues determine which specific emotion is induced, i.e., fear of an approaching werewolf (Felnhofer et al., 2015; Lin, 2017), the level of interactivity adds to the plausibility and realness of the VE (*plausibility illusion*; Slater, 2009), thereby increasing emotional involvement (Gorini et al., 2010; Diemer et al., 2015) and behavioral realism (Blascovich et al., 2002; Slater, 2009; Kisker et al., 2019a). In particular, the possibility to interact with and within the VE, and to be personally affected by occurring events overcomes the remoteness of conventional screen experiences (Slater, 2009; Lin, 2017; Lin et al., 2018; Lin, 2020; Kisker et al., 2020; Schöne et al., 2019). More than that, the experienced self-efficacy may reinforce the feeling of personal vulnerability to the occurring events (see Lin, 2017; Lin et al., 2018).

In a similar vein, participants of all groups felt generally present within the VE. However, the *hesitating* group felt

**TABLE 4 |** Test statistics for Mann-Whitney U-test regarding the FAA scores during epoch 34 and epoch 57.

| | | Descriptive statistics | | | Mann-whitney U-test | | | |
|---|---|---|---|---|---|---|---|---|
| | | *n* | *Md* | *SD* | *U* | *Z* | *p* | *effect size r* |
| Epoch 34 | Hesitating | 30 | −0.07 | 0.35 | 236.00 | −1.27 | 0.205 | 0.18[a] |
| | Hastening | 20 | −0.21 | 0.39 | | | | |
| | Hesitating | 30 | −0.07 | 0.35 | 316.00 | −1.42 | 0.155 | 0.19[a] |
| | Neutral | 27 | 0.08 | 0.41 | | | | |
| | Hastening | 20 | −0.21 | 0.39 | 158.00 | −2.41 | 0.016* | 0.35[b] |
| | Neutral | 27 | 0.08 | 0.41 | | | | |
| Epoch 57 | Hesitating | 31 | −0.01 | 0.25 | 188.00 | −2.35 | 0.019* | 0.33[b] |
| | Hastening | 20 | 0.07 | 0.27 | | | | |
| | Hesitating | 31 | −0.01 | 0.25 | 282.00 | −1.94 | 0.053 | 0.26[a] |
| | Neutral | 26 | 0.08 | 0.35 | | | | |
| | Hastening | 20 | 0.07 | 0.27 | 241.00 | −0.421 | 0.674 | 0.06 |
| | Neutral | 26 | 0.08 | 0.35 | | | | |

Note. *Kruskal-Wallis test revealed no group differences concerning further epochs. Significant differences between groups as indicated by Mann-Whitney* U*-test are marked (**p < 0.05; **p ≤ 0.01, ***p ≤ 0.001*). The respective descriptive statistics are given per group and the effect size* r *($\sqrt{\eta^2}$; a = small effect, b = medium effect) was determined. Positive FAA scores indicate withdrawal motivation, whereas negative FAA scores indicate approach motivation.*

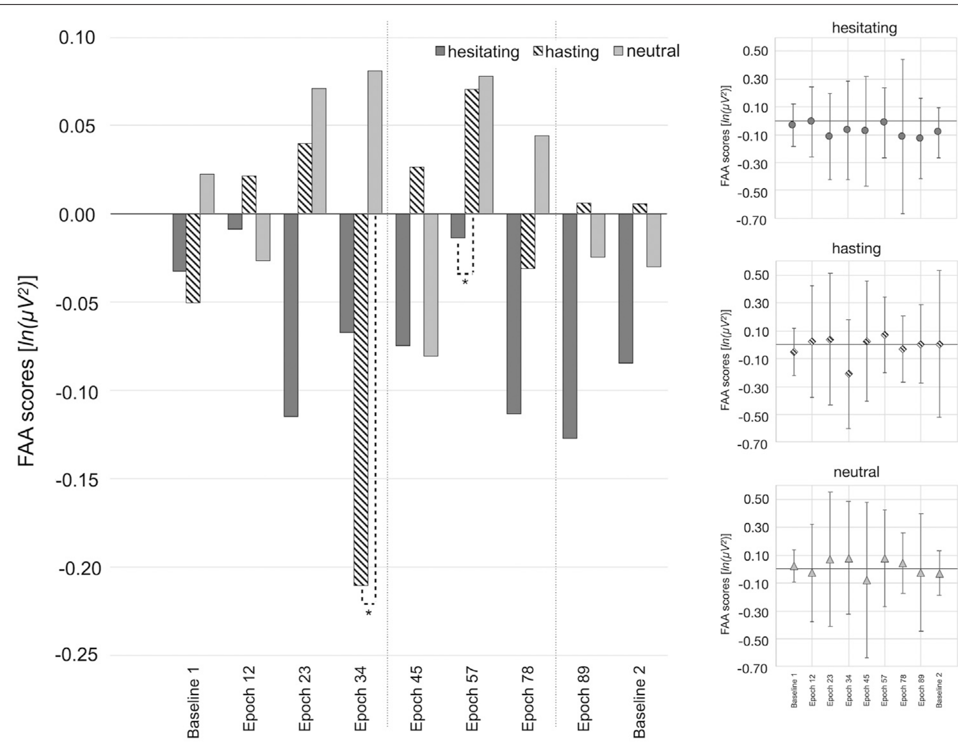


**FIGURE 3 |** FAA scores [ln (μV$^2$)] per subgroup and epoch of the cave exploration. Significant differences between groups are marked (**p* <0.05; ***p* ≤ 0.01, ****p* ≤ 0.001). Positive FAA scores indicate relatively greater right frontal cortical activity, whereas negative FAA scores indicate relatively greater left frontal cortical activity. The standard deviations from group mean are depicted as error bars in separate panels for increased visibility. The area between both dotted grey lines indicate the epochs during which the creature (werewolf/sheep) was visible.

more spatially present compared to both other groups. Numerous previous studies indicate a positive correlation between emotion and the feeling of presence, although the effective direction remains unclear (e.g., Riva et al., 2007; Diemer et al., 2015; Felnhofer et al., 2015; Kisker et al., 2019a). As both conditions allowed for equal levels of interactivity, spatial presence might be enhanced by emotional arousal, as the *hesitating* group felt the most frightened being the cave. A previous mixed reality study also only modified the visual impression, i.e., threatening vs. non-threatening, and concluded that the threatening condition corresponded with higher sensations of presence (Kisker et al., 2019a). However, although these findings may seem intuitive, our data does not allow a causal conclusion and could also be the result of interdependence of emotional experience and presence (Kisker et al., 2019a). Moreover, all groups exhibited equal levels of general presence, involvement, and realness, opposing the idea of modulation of presence by the emotional experience alone. Accordingly, factors other than emotion and immersion may have varying effects on the dimensions of presence, which should be objective to further research.

Surprisingly, both *negative* groups experienced a stronger increase in positive affect compared to the *neutral* group. This might, at first sight, seem counterintuitive. However, previous studies also found an increase in positive affect after unpleasant situations, ascribing this finding to relief, or even pride about having mastered an unpleasant, or in our case threatening, situation (Williams and DeSteno, 2008; Kisker et al., 2019a). Contrary to our expectations, the groups did not differ in the extent to which their HRVs changed. This is surprising given that the HRV parameter rmSSD tends to decrease during stressful situations (Castaldo et al., 2015). Therefore, we had expected that both *negative* groups would show a significant reduction in rmSSD compared to the *neutral* group. Instead, all groups showed a slight, not significantly different increase in rmSSD after exploring the cave compared to pre-exploration measurement. The increase in rmSSD, classically interpreted as reduced stress experience (Castaldo et al., 2015), might nevertheless reflect the changes in positive affect: The uncertainty about the cave's content and size before its exploration might have led to anticipatory stress, while the completion of the exploration might be experienced as a relief. However, the recording of the pre- and post-exploration phases might not have been sufficient to validly determine HRV parameters. Although rmSSD can be determined based on short-time measurements, it is usually preceded by resting phases (Castaldo et al., 2015). In our experiment, participants moved physically between measurements, which may have distorted the HRV assessment and limits its interpretability.

As all groups were equal in prior VR-experience, pre-experimental mood, trait anxiety, and further personality traits right before the VR exposure, differences between groups during or after cave exploration cannot be traced back to pre-existing differences, but the cave exploration. As the only, but a highly interesting exception, the *hesitating* group reported significantly lower impulsivity than both other groups and scored higher on the FFF-S, which indicates that their behavior is more likely to be determined by avoidance tendencies (Corr and Cooper, 2016; Pugnaghi et al., 2018) and corresponds to their initial reaction when detecting the werewolf.

## Authentic Fear Behavior in Immersive Virtual Reality

Most importantly, and going beyond matching self-reports, participants adapted their behavior immensely to their virtual surroundings. While the *neutral* group explored the cave rather casually, both *negative* groups exhibited distinct signs of acute and strong fear expressed via body language: They slowed down their pace, glimpsed around corners before taking the turn-off, or held their arms tight to their bodies in addition to verbal expressions of fear (see Adolphs, 2013). More than that, when being confronted with the werewolf, participants tended to advance toward the werewolf to get past it or to retreat, subdividing participants of the *negative* condition into two distinct subgroups: The *hesitating* group hesitated or even hid behind the former turn-off when detecting the werewolf, which corresponds to their lower levels of impulsiveness and more pronounced action control by avoidance. In contrast, the *hastening* group advanced toward the next turn-off before the werewolf approached any closer. These behavioral patterns were reflected in significantly higher exploration times in the *hesitating* group compared to both other groups. Slowing down their pace allows for greater vigilance and thus for potential hazards to be identified more quickly (Rinck et al., 2010). By hesitating to pass by the werewolf, the *hesitating* group stayed in the cave longer, whereas the *hastening* group, in comparison, abbreviated it by fleeing towards the cave's exit, thereby matching the *neutral* group's exploration time.

These behavioral adaptions point towards a crucial characteristic of VR setups: Since they are the subject of the virtual events and are personally involved in them (Slater, 2009; Slater and Wilbur, 1997; Kisker et al., 2020; Schöne et al., 2019), a behavior change is inevitable to deal with the threats within the cave (see Kisker et al., 2019a). The impression of realness must therefore have been so intense that the knowledge of being in a VR simulation was not sufficient to suppress the feeling of personal threat and a corresponding coping reaction (*place illusion;* Slater, 2009). As the mixed reality design allows for realistic sensorimotor actions, participants are enabled to react naturally and promptly when confronted with fear cues. In particular, realistic responses are enhanced by the impression of being directly and personally affected by the events within the VE (Slater and Wilbur, 1997; Nilsson, et al., 2016), for example the impression, that the werewolf can actually reach and harm them.

In standard laboratory settings, participants are supposed to indicate their natural response via substitutional responses: They are required to cognitively evaluate their initial response, determine the correct substitutional response, and then carry it out. In a real-life, threatening situation this chaining of cognitive evaluation and reaction might be dysfunctional. Rather, people would instinctively back off, freeze, or defend themselves physically as an initial impulse. Following LeDoux's (e.g. LeDoux, 1995; LeDoux, 1996; LeDoux, 1998; Debiec and LeDoux, 2004) theory on the fear circuit, VR setups would allow to access the immediate, emotional processing of stimuli. Conversely, capturing fear via substitutional responses would involve the slower cognitive path, as participants process their initial reaction and match it to an abstract, pre-set action to indicate how they feel. However, reactions triggered by VR events can only be accepted as equivalent to real reactions if virtual and real environments actually elicit identical reactions (Slater, 2009).

More and more studies indicate that VR settings not only lead to stronger emotional reactions compared to classical PC setups but that these reactions triggered by virtual events correspond to their real-life counterparts (Gorini et al., 2010; Higuera-Trujillo et al., 2017; Chirico and Gaggioli, 2019). Consequently, VR setups allow for a more naturalistic and non-mediated assessment of fear, offer an immense spectrum of response options, and involve the full body, mimicking the natural fear reaction to events in the real world (Bohil et al., 2011).

## Alpha-Asymmetry Models and Complex Behavioral Responses

Remarkably, the electrophysiological response distinguished between subgroups in two of the seven exploration sections based on the FAA. Based on existing models, and equivalent to Rodrigues et al. (2018), we expected relatively stronger left-frontal activity for approach-related behavior, i.e., negative FAA-scores when the *hastening* group approached the werewolf, and a relatively stronger right-frontal activity for avoidance-related behavior, i.e., positive FAA-scores for the *hesitating* group. Neutral behavior was not proposed to be linked to a distinct asymmetry.

The three subgroups were distinguishable directly after passing the corpse/tree trunk and hearing the werewolf/sheep (epoch 34), and when walking towards the werewolf/sheep (epoch 57). In particular, the *hastening* group differed significantly from the *neutral* group in epoch 34, exhibiting relatively greater left frontal activity, indicating approach motivation, while the *neutral* group exhibited relatively greater right frontal activity, indicating avoidance motivation (e.g., Harmon-Jones and Gable, 2018; Rodrigues et al., 2018). The *hesitating* group, descriptively exhibiting a slight approach motivation, did not differ significantly from any of the other groups. One might argue that both *negative* groups exhibited approach motivation towards the exit. The *neutral* group had no incentive to leave the cave early and was thus, possibly motivated to avoid the exit to explore the situation longer.

Moreover, during epoch 57, the *hastening* and *hesitating* groups differed significantly, with the *hastening* group exhibiting avoidance motivation and the *hesitating* group exhibiting approach motivation. On the one hand, the *hastening* group's avoidance motivation might be linked to their instant initiation of an escape from the current cave section towards the exit before the werewolf comes any closer. The *hesitating* group's approach motivation, on the other hand, might reflect the emotional self-control to pass the werewolf to reach the exit after initially hiding or hesitating. The latter interpretation supports recent models that associated FAAs with inhibitory top-down regulation of emotion (Lacey et al., 2020; Schöne et al., 2015). The *neutral* group exhibited equal levels of avoidance motivation compared to the *hastening* group, which might indicate avoidance of leaving the cave early. However, during this epoch, none of the groups knew that the exit was behind the next turn. Therefore, the previous interpretation seems rather speculative.

In terms of the revised sensitivity theory (Gray and McNaughton, 2000), Wacker and colleagues (Wacker et al., 2003; Wacker et al., 2008) introduced the behavioral inhibition model of anterior asymmetry (BBMAA). The BBMAA relates relatively greater left frontal activity, as in the *hesitating* group, to the activation of the fight-flight-freeze-system (FFF-S), responding to negative stimuli and threat, whereas relatively greater right frontal activity, as in the *hastening* group, might relate to the behavioral inhibition system (r-BIS), allowing for superordinate emotion-regulation and behavioral control (Gray and McNaughton, 2000). According to the group's behavioral responses, hesitating and hiding from the werewolf would fit with the FFF-S and might, in line, be interpreted as active behavior to avoid the fear cue. Vice versa, accelerating their pace to instantly pass the werewolf would fit with the r-BIS. But notably, the respective asymmetry is proposed to indicate passive behavior (Wacker et al., 2003; Rodrigues et al., 2018), standing in stark contrast to instantly approaching the werewolf and passing it. To hasten past the werewolf is undoubtedly effective to escape the threatening situation and thus may be interpreted as avoidance rather than approach. However, the *hastening* group seems to be primarily driven by emotion regulation, as they do not hesitate, but instantly move towards the werewolf. Hence, the synthesis of this behavior and FAA might rather relate to effortful control of emotion (Lacey et al., 2020; Schöne et al., 2015), allowing to escape from the threatening situation instead of freezing.

None of the aforementioned explanatory approaches covers that the groups' FAAs did not differ significantly for the greater part of the cave exploration. Despite of showing such a variety of and strongly pronounced behavioral responses, participants of all groups could only be distinguished in two of the seven cave sections based on the FAA data. This was particularly surprising as the *negative* condition triggered intense negative affect, as well as a high motivation to leave the cave early, which was significantly reflected in self-reports and behavior. Walking towards a corpse and sounds of crying compared to a tree trunk and wind sounds were not accompanied by significantly different FAA scores between groups. Even more, the *hesitating* group descriptively exhibited relatively greater left frontal activity throughout the cave exploration which is, according to the most well-known models, associated with approach motivation or positive affect (e.g.,Davidson et al., 1990; Gable and Harmon-Jones, 2008; Harmon-Jones and Gable, 2018). For obvious reasons, the valence model (e.g., Davidson et al., 1990; Davidson, 1998) does not correspond to the observed behavioral responses, while one might speculate whether the observed approach motivation might reflect to urge to reach the exit.

Hence, the FAA data collected in our immersive VR setup could be aligned with previous models only to a very limited, inchoate degree. Although initial desktop-VR studies provided evidence that the behavioral patterns in a video game trigger FAAs corresponding to the motivational model (Rodrigues et al., 2018), we were unable to replicate these findings in a highly immersive VR setup.

## The Special Role of Immersive Virtual Reality Setups

Even though we could not fully reconcile the self-reports and behavioral data with the obtained FAA data, we would like to consider the following points as potential, but not incontrovertible explanations for the observed discrepancies:

As previously speculated, the *hesitating* group exhibiting an approach motivation throughout the cave exploration might be attributed to having a strong motivation in terms of approaching the cave's exit. This assumption presupposes that FAAs do not reflect an emotional or motivational response to distinct fear cues, but a higher goal, supporting the idea that the FAA dynamics might reflect top-down inhibitory executive processes, rather than motivational tendencies *per se* (Schöne et al., 2015). In line, the neutral cave might elicit FAAs since the aim of finding the exit is pursued, although the neutral environment would not in itself provide a specific incentive to do so. However, as leaving the cave seems much more urgent in the *negative* condition, it would still have been expected that the FAAs elicited by the *neutral* and the *negative* conditions would be significantly different.

Apart from that, the best-known FAA models are not entirely consistent with each other: each model has been repeatedly lined with evidence, revised, or even overruled (for review see e.g., Harmon-Jones and Gable, 2018; Lacey et al., 2020). Considering this limited consistency, it is less surprising that the FAA data obtained from a very different setup compared to the conventional assessments does not match previous models one-to-one. In terms of emotion induction methods, the discrepancy might arise from the multidimensional nature of VR setups: a major advantage of classical laboratory experiments is the possibility to isolate relevant processes (Kvavilashvili and Ellis, 2004; Parsons, 2015). In contrast, VR setups, like real experiences, are multidimensional (Bohil et al., 2011; de la Rosa and Breidt, 2018; Pan and Hamilton, 2018) and, as we argued, facilitate realistic reactions (e.g., Blascovich et al., 2002; Slater, 2009; Kisker et al., 2019a). Accordingly, rather weak signals like the FAA may play in concert with further cognitive and emotional processes in complex, realistic situations (see Bohil et al., 2011). Thus, classical measurements as applied in conventional setups might not adequately capture FAAs under more naturalistic conditions and might need adaption for sufficient application.

In a similar vein, the assignment of FAAs to certain emotional or motivational states might not be unrestrictedly generalizable to complex behavioral reactions going beyond abstract responses: Models concerning the FAA are based on highly standardized laboratory setups, which strongly limit the behavioral response options to rather abstract stimuli presented on a screen (e.g., Wacker et al., 2008; Parsons, 2015). So-called desktop-VR settings, being somewhat more immersive, still reduce the behavioral response options, e.g., to movements of a joystick (e.g., Rodrigues et al., 2018; Brouwer et al., 2011). In contrast, immersive VR setups, such as the physical exploration of a cave, allow for multisensory, realistic sensations and significantly broader and non-mediated behavioral reactions (e.g., Rinck et al., 2010; Lin, 2017). Accordingly, the reduction of complex reactions to a single electrophysiological marker seems too abstract for realistic conditions (e.g., Lange and Osinsky, 2020; Bohil et al., 2011).

One might argue that movement-induced artifacts or wearing an HMD might overshadow significant differences between groups. However, recent methodological examinations demonstrated that mobile EEG obtains good data quality during walking even in single-trial setups (Debener et al., 2012; Nathan and Contreras-Vidal, 2016), and wearing common HMDs does not impact the EEG's signal quality regarding frequency bands below 50 Hz (Hertweck et al., 2019). Accordingly, it seems unlikely that differences between groups would have been overshadowed.

Summing up, the source of the discrepancy between behavioral responses and canonical FAA models is not yet conclusively understood. The differences found between groups seem to be mainly attributable to top-down emotion regulation (Lacey et al., 2020; Schöne et al., 2015). However, based on the aforementioned considerations, we assume that the canonical FAA and respective models cannot be applied to complex, holistic behavior without restriction or adaption, as FAAs have so far been investigated by means of abstract responses. Rather, the complexity of realistic behavioral responses may not be fully predicted by a single, very specific electrophysiological marker (Bohil et al., 2011; Lange and Osinsky, 2020). Accordingly, contemporary FAA models offer an avenue to explore approach and avoidance behavior, but under realistic conditions, FAAs may not be as predominant as previous models suggest.

## Ethical Challenges of Using VR as an Experimental Tool

With the high level of realism that VR offers, the ethical and moral responsibility in the implementation of experimental studies increases at an exponential rate. Many objectives could potentially be investigated more naturally and efficiently when implemented via realistic experimental setups. Nevertheless, the participants' safety must always come first, and it must be carefully considered whether the gain from extended knowledge justifies the participants' potential strain.

Despite ethical approval, exploring an unknown cave without warning that, and which negative stimuli would await the participants was a significant strain on them. Five of the 59 participants exploring the negative cave terminated the experiment at the first sight of either the cave's entrance ($n$ = 1) or the werewolf ($n$ = 4). Although being anecdotal evidence only, some participants whimpered heavily, others engaged in self-calming strategies, like telling themselves repeatedly that it was only a game to break immersion. One participant even started crying when detecting the werewolf, three participants reported having nightmares the night after the experiment. To put it bluntly, we were rather surprised that so many participants completed the cave exploration while experiencing intense fear and distress, although they were distinctly and repeatedly instructed that they could stop the experiment immediately if they felt uncomfortable.

Some VR horror games even explicitly warn that the experience in VR is more intense compared to conventional games and might cause significant psychological strain. Attending and staying in such simulations could be attributed to the general appeal of mediated horror content (Lin et al., 2018). Considering that VR setups are assumed to evoke real-life behavior (e.g., Slater, 2009; Kisker et al., 2019a), emotions (e.g., Higuera-Trujillo et al., 2017; Chirico and Gaggioli, 2019), and transfer such experiences to real-life in terms of learning (e.g., Ragan et al., 2010) and mnemonic processes (e.g., Kisker et al., 2019b; Schöne et al., 2019; Kisker et al., 2020), it is an effective tool for e.g., exposure therapy (for review see e.g., Botella et al., 2017). But on the flip side of this coin, VR has not only the potential to treat but also to cause psychological dysfunction, such as PTSD-related symptoms (e.g., Dibbets and Schulte-Ostermann, 2015). The blurring of the mental border between virtual and real, and the resulting costs and benefits for all parties involved, must therefore be weighed very carefully on a case-by-case basis (for an in-depth discussion of ethics of virtual reality see e.g., Parsons, 2019; Slater et al., 2020).

## CONCLUSION

Our results demonstrate that the employed VR setup facilitates realistic fear responses beyond affective responses: Exceeding the participants' self-reports of intense fear in both *negative* subgroups, they adapted their behavior to the encountered situation. While conventional setups can only operationalize the participants' substitutional response, e.g., in the form of a keystroke, VR setups allow for an immediate expression and assessment of the comprehensive fear response, e.g., by physically backing away from a stimulus. To our best knowledge, this study is the first one to investigate complex behavioral fear responses employing a mixed VR setup and thus, complements previous findings. Participants exploring the negative cave either quickly advanced toward the werewolf to get past it or retreated when spotting the werewolf. In stark contrast, participants exploring the neutral cave behaved casually and showed no particular signs of fear or discomfort. Overall, these behavioral responses exhibited in the cave resemble lifelike responses on an affective but foremost on the behavioral level, extending scientific evidence for VR-based research's feasibility and effectiveness.

Moreover, no previous study has collected electrophysiological correlates of approach and avoidance under similarly immersive conditions. The different behavioral patterns were reflected in the electrophysiological responses. Specifically, the FAA discriminated between the advancing (*hastening* group) and retreating (*hesitating* group) behavior as they walked towards the werewolf in the *negative* condition, indicative of differences in emotion regulation. Furthermore, differences between the *hastening* and the *neutral* groups were obtained only at rare occasions. Especially the absence of effects is remarkable, and albeit their ability to discriminate between different motivational or affective states, the remaining FAAs could not be reconciled with contemporary FAA models. This discrepancy could be attributed to the FAA models being based on data obtained under abstract laboratory conditions. The study at hand further incorporates the participants' complex behavioral responses, possibly affecting motivational tendencies.

Hence, putting laboratory-based models to the test under realistic conditions shows that they may not unrestrictedly predict real-life behavior. Yet, they provide a baseline for further refinement of experimental findings, which can be complemented by VR-based research. Accordingly, our findings demonstrate the high potential of implementing VR technology in experimental settings to increase the ecological validity of scientific findings. VR allows for non-mediated and life-like affective and behavioral responses and scientific measurements of real-world processes.

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://osf.io/jwt7d/?view_only=92bda76c430247bca3a93eacf4567813

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the local ethic committee of Osnabrueck University, Germany. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

The study is based on a concept drafted by BS. All authors contributed to the study design. KF, MK, FT, PO, and NL developed the Unity VR environment and the physical replica under supervision of BS and JK. JK and LL integrated EEG and ECG applications into the Unity environment. Testing and data collection were performed by JK, LL, and KF. CG developed the application "Cagliostro" for the video rating of the participant's behavior. Data analyses were performed by JK under the supervision of BS and TG. JK and LL performed the data interpretation under the supervision of BS, TG, and RO. JK drafted the manuscript, LL revised the manuscript. BS, TG, and RO provided critical revisions. All authors approved the final version of the manuscript for submission.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2021.716318/full#supplementary-material

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BRIEF RESEARCH REPORT
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# Virtual Reality and EEG-Based Intelligent Agent in Older Adults With Subjective Cognitive Decline: A Feasibility Study for Effects on Emotion and Cognition

*Marc Cuesta*[1], *Lynn Valeyry Verty*[1,2], *Hamdi Ben Abdessalem*[3], *Alexie Byrns*[3], *Marie-Andrée Bruneau*[1,4], *Claude Frasson*[3] *and Sylvie Belleville*[1,2]*

[1]*Research Centre, Institut Universitaire de Gériatrie de Montréal, Montreal, QC, Canada,* [2]*Department of Psychology, Université de Montréal, Montreal, QC, Canada,* [3]*Department of Computer Science and Operational Research, Université de Montréal, Montreal, QC, Canada,* [4]*Department of Psychiatry and Addictology, Université de Montréal, Montreal, QC, Canada*

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***Edited by:***
*Ali Oker,*
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*University of Barcelona, Spain*

****Correspondence:***
*Sylvie Belleville*
*sylvie.belleville@umontreal.ca*

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**Objectives:** Immersive virtual reality has tremendous potential to improve cognition in populations with cognitive impairment. We conducted a feasibility and proof-of-concept study to assess the potential of virtual reality and electroencephalography, with or without an intelligent agent, that adapts the presented material to the emotions elicited by the environment.

**Method:** Older adults with subjective cognitive decline recruited from the community received a virtual reality-based intervention taking place in one of two virtual environments, a train (Part 1, N = 19) or a music theatre, complemented by the intelligent agent (Part 2, N = 19). A comparative control group (N = 19) receiving no intervention was also included. All participants completed measures of affect and cognition before and after the intervention. The intervention groups completed measures of cybersickness and user experience after the intervention.

**Results:** Participants did not suffer from increased cybersickness following either intervention. They also reported a positive to highly positive user experience concerning the following aspects: attractivity, hedonic quality-identity and hedonic quality-stimulation. The measures of affect showed no pre-post change when comparing either intervention to the control condition. However, a reduction of negative affect was observed following the train intervention for participants with a high self-reported negative affect at baseline. Finally, there was a significant improvement in working memory when comparing either intervention group to the control condition.

**Conclusion:** Our results support the feasibility and tolerability of the technology, and a positive impact on cognition, paving the way for a larger-scale randomized clinical trial to confirm efficacy.

**Keywords: cognition, emotions, subjective cognitive decline, cybersickness, user experience, virtual reality**

## INTRODUCTION

Immersive virtual reality (VR) has been increasingly used in clinical neuropsychology research and to treat neuropsychiatric symptoms (Maples-Keller et al., 2017; Ouellet et al., 2018; La Corte et al., 2019; Corriveau Lecavalier et al., 2020; Dermody et al., 2020). With VR, the user is usually immersed in a virtual environment (VE) through a motion-tracked head-mounted display and controllers, and therefore isolated from external visual and auditive distractions. The user can engage and interact with the environment: it is possible to look around by moving the head, explore by walking and interact with objects by grabbing and throwing for instance. These features create a feeling of presence, i.e., a feeling of being immersed in the environment displayed. VR can be used to incorporate cognitive and physical demands within virtual scenarios that mimic situations that a person faces in his/her everyday life. Thus, VR is extremely promising to increase the ecological validity of measures and interventions.

Given its malleability and various functionalities, VR has become one of the most compelling developments in rehabilitation for diverse populations including older adults. VR has many assets: it allows a high level of interaction in a safe environment; it can be adapted to various characteristics and individual needs; and it offers the potential to develop engaging and effective training with optimal transfer of gains to daily life. This technology could therefore be particularly useful in older adults with or without cognitive impairment and could be associated with other approaches to optimize cognitive vitality and/or prevent cognitive decline. Intervention and feasibility studies using VR have shown encouraging results in this context. The technology has been well tolerated by older adults (Ouellet et al., 2018; Corriveau Lecavalier et al., 2020; Dermody et al., 2020), and was found to contribute to programs aiming to improve cognitive function (Dermody et al., 2020), reduce anxiety disorders and possibly depression (Maples-Keller et al., 2017). However, more interventional and feasibility studies are needed in older adults to assess usability, accessibility and user experience. These studies will address whether the technology is considered accessible and easy to use, and ultimately adopted by older adults either in a clinical context or everyday life (e.g., at home) (Proctor et al., 2011; Holthe et al., 2018).

It is also critical to expand the use of VR to a diversity of older adults, including those who start to experience cognitive challenges or develop psychiatric symptoms. Older adults with subjective cognitive decline (SCD) complain and worry about their cognition. People with SCD perform normally on current neuropsychological tests but they progress to dementia at a higher rate than people with no subjective impression of a decline. Many may be in a very mild phase of Alzheimer's disease or a related disorder, prior to the presence of cognitive impairment (Caillaud et al., 2020). This phase may be ideal to provide cognitive training because older adults with SCD are concerned and aware, and still have the cognitive capabilities to learn and apply new strategies (Lin et al., 2018). Therefore, older adults with SCD are excellent candidates to study VR-based intervention programs.

Because VR immerses individuals into vivid real-life scenarios, it is particularly important to adapt these to individual preferences. One promising avenue is using an electroencephalogram (EEG) to measure brain waves as participants are immersed in the VE and use the signal to contiguously adapt the environment to the participant's emotional reaction. Using artificial intelligence, this technique can be used to personalize the VE and its contents in response to the user's emotional state. Recently, Abdessalem and Frasson developed an intelligent agent system, which is a system that can adapt the presentation of content based on the behaviour and emotions of the VR user. EEG readings are analysed in real-time and the content is adapted based on the recorded brain waves with the goal of creating positive emotions (Abdessalem and Frasson, 2017). The system could track the user's excitement and frustration after extraction from the EEG. The authors reported changes in excitement and frustration of younger adults in response to changes in speed and difficulty of a VR game triggered by the intelligent agent. By having a positive impact on emotions, this approach could also positively impact cognition. Negative emotions have been associated with reduced cognitive and memory performance, and positive emotions with increased performance, particularly for working memory (WM) and controlled attention tasks (Williams et al., 1996; Blair et al., 2007; Verbruggen and De Houwer, 2007; Conway et al., 2013; Su et al., 2017; Garrison and Schmeichel, 2019). Emotions have therefore been proposed to have a mediating effect on these cognitive components. Older adults with SCD have higher levels of neuropsychiatric symptoms during the course of their cognitive decline (Robert et al., 2006; Köhler et al., 2010; Guercio et al., 2015; Lanctôt et al., 2017; Sherman et al., 2018), which in turn impact their emotional state. Therefore, they could greatly benefit from a technology that adapts the presentation of stimulus to its emotional impact. This intelligent agent combined with VR may support more personalized rehabilitation strategies in people with cognitive decline. These technologies could also be particularly useful for older adults who may have negative reactions to technology-based interventions but whose cognitive limitations prevent them from expressing their preferences. Thus, the combined use of the VR and EEG-based technology could be beneficial to promote well-being through emotional state and cognition improvement.

As a first step toward developing a VR- and EEG-based intelligent agent system, we created two VEs (Biamonti et al., 2014; Gómez Gallego and Gómez García, 2017): 1) a train (train intervention) and 2) a music theatre, complemented by the intelligent agent (music intervention). We tested the two VEs during a feasibility study in older adults with SCD[1] and aimed to determine tolerability and user experience after their completion. For the proof-of-concept study, preliminary data on the VEs' impact on self-reported emotion and objective measures of attention and WM, two cognitive domains that have been found to be sensitive to emotional variation (Abdessalem

[1]Partial data on emotional EEG measures were published in conference proceedings (Abdessalem et al., 2020; Byrns et al., 2020)

et al., 2020; Byrns et al., 2020), were compared to a no-contact control condition.

# MATERIAL AND METHODS

## Participants

Included participants were French-speaking, aged 60 and over, with normal or corrected-to-normal vision and hearing, and met recognized criteria for SCD (Belleville et al., 2019). Participants were excluded from the study if they had a history of major psychiatric illness, neurological disorders that could explain the cognitive complaint, alcoholism, significant impairment of physical mobility or the use of hands and known cybersickness or motion sickness. In total, 45 older adults with SCD participated in the study. Nineteen participants (11 female) were included in the train intervention, and nineteen (13 female) were included in the music intervention, of which twelve had also participated in the train intervention. Nineteen people (16 female) were included in the control condition. The sample size was not determined from a power analysis as this was a proof-of-concept study aiming to provide information on tolerability and user experience, and therefore did not target efficacy.

All participants were recruited through the bank of participants of the Institut universitaire de gériatrie de Montréal Research Centre (CRIUGM). Initial contact with prospective participants was conducted over the phone and individuals deemed eligible were invited to visit the CRIUGM. During their visit, they received the information and consent form and completed a brief clinical examination: MoCA (Nasreddine et al., 2005); WMS-IV Logical Memory subtest; Diagnostic Criteria for Apathy (DCA) (Robert et al., 2018); Mild Behavioral Impairment Checklist (MBI-C) (Ismail et al., 2017); Big Five Personality Test (50 items) (Goldberg, 1992).

The study was done in accordance with the Declaration of Helsinki and approved by the Research Ethics Board (REB) - vieillissement-neuroimagerie - of the CIUSSS-CSMTL (application #18–34).

## Design

Both the interventions and the control condition were completed during a single visit to the CRIUGM. For participants who completed both the train and the music interventions, there was a delay of at least 3 months between visits. Participants began each visit with a pre-intervention assessment, during which they filled out questionnaires assessing cybersickness and emotions. They then completed six computerized cognitive tasks to measure WM and attention. Participants were then exposed to one of the VEs, which lasted 5 minutes for the train and 10 minutes for the music intervention. Finally, participants completed the post-intervention assessment, including measures of cybersickness and user experience (first goal), as well as questionnaires on emotions and cognitive tasks (second goal). Participants from the control group completed cognitive tasks and questionnaires on emotions twice, separated by a 10-min discussion with a member of the research team on topics unrelated to the study. Parallel versions of the cognitive tasks were used at pre- and post-intervention to reduce learning effects. These were presented in a fixed order across participants.

## Interventions

Both VEs were created with Unity 3D and presented with the Fove0 VR headset (Fove Inc., Torrance, CA, US). Concurrently, brain waves were recorded with the Epoc + portable EEG headset (Emotiv, San Franscisco, CA, US) (Abdessalem et al., 2020; Byrns et al., 2020). The headset includes 14 electrodes spatially organized according to the international 10–20 system (AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8, T7, T8, O1, O2). Raw EEG was captured at the rate of 128Hz and provided the power of five frequency bands (theta, alpha, low and high beta, gamma). EEG recording was supplemented by an intelligent agent in the music intervention only.

In the train intervention, the participant was seated in a virtual train, where he/she could see different changing landscapes (e.g., forest, snowy mountains, sunny desert, **Figure 1A**). Participants could turn their head to explore the environment around them. The speed of the train was the same for all participants and was set to allow a proper observation of the environment without being too slow. There was no intelligent agent, as our goal was to assess the feasibility and experience related to a realistic and peaceful travel environment.

In the music intervention, participants were seated in a theater and were presented with eight different 30 s musical pieces from different repertoires (e.g., Clair De Lune, Debussy; La Vie En Rose, Piaf (de la Torre-Luque et al., 2017)) accompanied by animated instruments and firework-like visual effects (**Figure 1B**) (Valdez and Mehrabian, 1994). While pieces were being played, the intelligent agent recorded brain waves and analyzed them to provide an estimate of its emotional impact. This information was used to determine the piece that was associated with the highest positivity value. This piece was then presented for 2 minutes.

## Outcome Measures

### Cybersickness and User Experience Questionnaires

Cybersickness was measured with the Cybersickness Questionnaire (CSQ (Sevinc and Berkman, 2020)) using nine items rated on a 3-point Likert scale from 0 (not at all) to 2 (moderately). The CSQ comprises two subscales, “dizziness” (maximum scores: 7.52) and “difficulty in focusing” (maximum score: 5.66). The AttrakDiff 2 scale is a validated tool to evaluate user experience (Lallemand et al., 2015). The scale includes 28 items combined to measure different dimensions: Pragmatic Quality (PQ), Attractiveness (ATT) and Hedonic Quality (HQ), which is subdivided into Stimulation (HQ-S) and Identity (HQ-I) dimensions. Each item consisted of a pair of opposed adjectives ranked with a score from -3 (for example extremely unpleasant) to +3 (for example extremely pleasant). A score of 0 means that the item was considered neutral (for example neither unpleasant nor pleasant). Data are presented using the scores on individual word-pairs, the combined scores for the four categories (PQ, ATT, HQ-S, HQ-I) or by plotting HQ against PQ (known as the portfolio results).

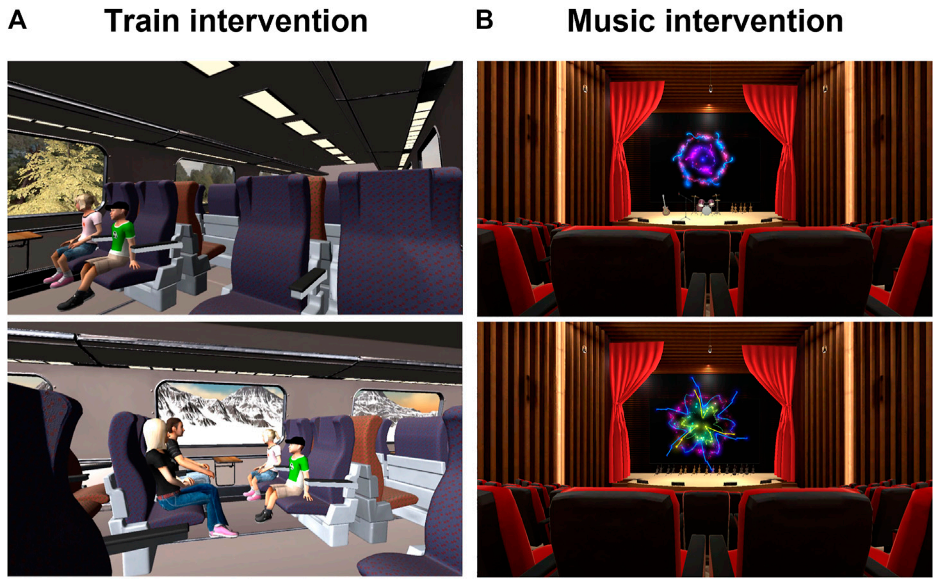


**FIGURE 1 |** Virtual train and music theatre. Examples of what a user can experienced when immersed in the virtual train **(A)** or the virtual music theatre **(B)**.

## Affect and Cognitive Measures

The *positive and negative affect schedule (PANAS)* scale (Watson et al., 1988) comprises 10 items measuring positive affect (PA) and 10 measuring negative affect (NA) (maximum score for each scale = 50).

Four computerized WM tasks and two attentional tasks were used. In WM task 1, participants were asked to memorize six images of objects and written words (maximum score = 6) (Nasreddine et al., 2005). In WM task 2, they had to memorize a sequence of two sets of four and six circles presented one by one (maximum score = 10) (Nasreddine et al., 2005). WM task three involved memorizing a set of three images presented simultaneously. This task was repeated twice (maximum score = 2) (Nasreddine et al., 2005). In WM task 4, participants were asked to record two series of orally-presented digits on a numerical pad (first series: five digits, order of presentation; second series: three digits, backward order; maximum score = 8) (Leark et al., 2007). In attention task 1, participants were asked to indicate when the letter "A" was displayed in a series of presented letters ("A" presented 11 times among a series of 30 letters: maximum score = 11) (Asato et al., 2006). In attention task 2, they were presented with four letters and asked to indicate the letter corresponding to the first letter of the name of an image that was previously presented. This task was repeated six times (maximum score = 6) (Leark et al., 2007).

## Statistical Analyses

All statistical tests were done using IBM SPSS Statistics V26 (Armonk, NY, United States). They were two-tailed and a $p$ value <0.05 was chosen for statistical significance. All analyses were done separately for the train and music interventions. Ordinal data were analyzed with parametric tests rather than non-parametric scales as they provide a more in-depth analysis, and they are robust to violations of data assumptions and are more versatile, powerful and comprehensive (Norman, 2010).

Group differences for clinical characteristics were tested between each intervention group and the controls at baseline, with a t-test or $\chi^2$ test as appropriate. For the cybersickness scale, the pre-post score difference was tested for each subscale using paired-sample t-tests.

Data for the word-pair dimensions and categories were analyzed with confidence intervals (CI) for the AttrakDiff two scales, which are only measured at post-intervention. A score was considered as significantly different from a neutral assessment when the 95% CI did not cross zero. Significantly different scores that were larger than two or minus two were considered as highly positive or highly negative, respectively. To assess the intervention effect on the PANAS, as PA and NA scales are correlated (Crawford and Henry, 2004), we used MANOVAs with group (train or music vs control) as a between-subject factor and time (pre-vs post-) as a within-subject factor. Per-item analysis of the PA and NA scales were also performed with MANOVAs. We conducted additional exploratory analyses to better assess pre-post intervention effects on PA and NA. We categorized participants with low vs high baseline PA and NA values and analyzed these data with mixed ANOVAs using baseline PANAS score (low vs high) as a between-subject factor and time (pre-vs post-) as a within-subject factor. This was done separately for each group (train, music and control) as our sample size was too small to test three-way interactions. Least Significant Difference (LSD) post-hoc tests were conducted when a significant baseline

**TABLE 1 |** Participants' demographic and clinical characteristics.

| | | Train intervention | | Music intervention | | Control | | Train vs control | Music vs control |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean (SD) or N | Range | Mean (SD) or N | Range | Mean (SD) or N | Range | *p* value | *p* value |
| Age (y) | | 69.7 (5.5) | 62–81 | 72.3 (5.8) | 62–86 | 72.4 (6.5) | 62–86 | 0.17 | 0.96 |
| Sex (male N, female N) | | 8, 11 | N/A | 6, 13 | N/A | 3, 16 | N/A | 0.07 | 0.25 |
| Education (y) | | 15.3 (1.8) | 11–18 | 15.9 (2.4) | 11–21 | 16.1 (2.4) | 12–20 | 0.29 | 0.89 |
| MoCA score (/30) | | 28.2 (1.4) | 25–30 | 27.9 (1.4) | 25–30 | 28.7 (1.2) | 26–30 | 0.27 | 0.07 |
| Logical memory subtest (/25) | Immediate | 15.5 (3.1) | 10–22 | 15.6 (3.1) | 11–22 | 17.3 (3.3) | 11–21 | 0.10 | 0.11 |
| | Delayed | 14.5 (3.9) | 8–22 | 14.9 (4.0) | 8–22 | 16.8 (3.9) | 9–19 | 0.08 | 0.16 |
| ADC diagnostic (N) | | 0 | N/A | 0 | N/A | 0 | N/A | N/A | N/A |
| MBI-C (/102) | | 1.9 (3.1) | 0–9 | 3.4 (3.5) | 0–10 | 2.8 (4.8) | 0–17 | 0.47 | 0.70 |
| Big-Five Personality Test (/40) | Extraversion | 19.7 (6.9) | 11–31 | 21.8 (5.9) | 13–30 | 17.3 (5.6) | 4–25 | 0.24 | <0.05 |
| | Agreeability | 31.0 (2.5) | 27–35 | 31.3 (3.1) | 23–36 | 28.2 (3.3) | 20–33 | <0.01 | <0.01 |
| | Conscientiousness | 26.2 (6.8) | 5–34 | 27.5 (7.0) | 5–37 | 26.8 (4.1) | 20–33 | 0.71 | 0.74 |
| | Neuroticism | 23.6 (7.3) | 5–38 | 22.8 (7.3) | 5–38 | 27.1 (5.7) | 11–35 | 0.11 | 0.05 |
| | Openness to Experience | 26.6 (4.4) | 20–40 | 26.7 (4.0) | 17–36 | 25.8 (4.5) | 15–35 | 0.59 | 0.52 |

*ADC, apathy diagnostic criteria; MBI-C, Mild Behavioral Impairment-Checklist; MoCA, montreal cognitive assessment; N/A, not applicable; SD, standard deviation; y, years.*

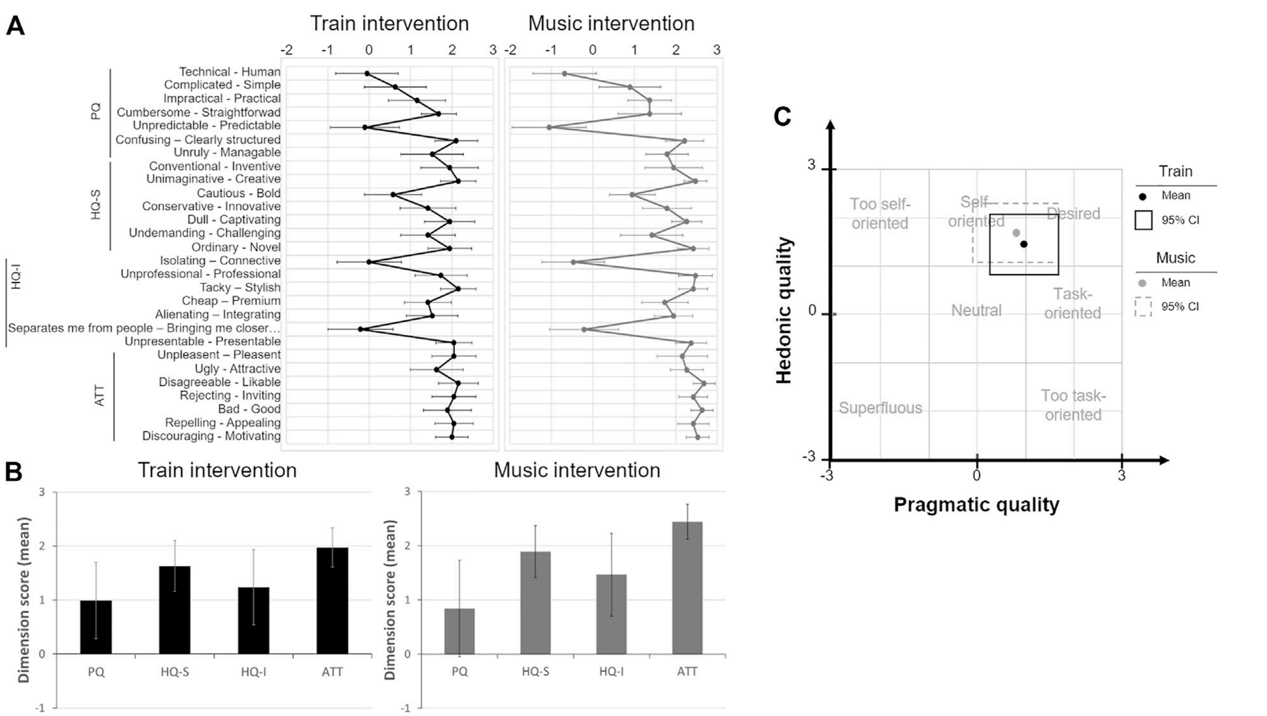


**FIGURE 2 |** User experience for the train and music intervention Mean scores (±95% CI) for the AttrakDiff two word-pairs **(A)** and dimensions **(B)** for the *train* (dark black symbols and lines) and *music* intervention (grey symbols and lines). In **(C)**, PQ and HQ are plotted on the *x* and *y* axes, respectively. Black and dashed grey boxes represent the 95% CI for the *train* and *music* interventions, respectively. Framed zones represent different characteristics based on the relationship between PQ and HQ (e.g., the virtual environment is considered as “desired” when a score is located within the box with scores ranging from two to three in both PQ and HQ). ATT, Attractivity; CI, Confidence Interval; HQ-I, Hedonic Quality-Identity; HQ-S, Hedonic Quality-Stimulation.

score x time interaction was found. The intervention effects on cognitive measures were analyzed separately for each task and intervention group using mixed ANOVAs with group (train or music vs control) as a between-subject factor and time (pre-vs post-) as a within-subject factor. LSD post-hoc tests were conducted when a significant interaction was found.

# RESULTS

## Participants' Demographic and Clinical Characteristics

Baseline characteristics of participants were similar when comparing controls to the train or music intervention groups, except for two personality traits (**Table 1**): Participants from the control condition were less extraverted than these from the music intervention ($p < 0.05$) and less agreeable than these from both train and music interventions ($p < 0.01$ for both).

## Cybersickness Symptoms and User Experience

No significant post-vs. pre-intervention differences were found for both vertigo (0.23 (0.37) vs. 0.33 (0.68) for train intervention; 0.59 (0.81) vs. 0.80 (0.96) for music intervention) and difficulty to focus (0.13 (0.33) vs. 0.15 (0.40) for train intervention; 0.38 (0.58) vs. 0.64 (0.77)) for music intervention) subscales of the CSQ. Results on the user experience questionnaires are shown in **Figures 2A,B**. For both environments, a few word-pairs were considered in the neutral range (with 95% CI between -1 and 1): *unpredictable-predictable*; *isolating-connective*; *separates me from people/ brings me closer to other people*. The *technical-human* word-pair was also perceived as neutral for the train environment while the music environment was considered technical. Several other word-pairs describing the music intervention were ranked with a highly positive score, while this was not the case for the train intervention (**Figure 2B**). All user experience dimensions were perceived as positive or highly positive, except for PQ in the music intervention. The portfolio presentation (**Figure 2C**), which focuses on HQ and PQs, indicates that both interventions were judged as self-oriented or desired. The train intervention could also be characterized as neutral or task-oriented.

## Affect Measures

The MANOVA on the PANAS scores for the train intervention revealed no significant main effect of group, F (2,32) = 2.24, $p$ = 0.12, Wilk's $\Lambda$ = 0.88, time, F (2,32) = 0.10, $p$ = 0.90, Wilk's $\Lambda$ = 0.99, or group x time interaction, F (Valdez and Mehrabian, 1994; Dermody et al., 2020) = 0.49, $p$ = 0.62, Wilk's $\Lambda$ = 0.97 (**Supplementary Figures 1A,B**). For the music intervention, the MANOVA yielded no significant main effect of group, F (2,35) = 0.88, $p$ = 0.42¸Wilk's $\Lambda$ = 0.95), time, F (2,35) = 0.46, $p$ = 0.64, Wilk's $\Lambda$ = 0.97), or group × time interaction, F (2,35) = 0.62, $p$ = 0.54, Wilk's $\Lambda$ = 0.97) (**Supplementary Figures 1C,D**). No significant effect was found for any of the fixed factors and their interaction when analyzing the different NA and PA items in both the train and the music intervention (Supplementary Table 1), except for a main effect of time in the NA items for the music intervention (F (10,26) = 2.41, $p < 0.05$, Wilk's $\Lambda$ = 0.52; **Supplementary Table S1**).

The ANOVA examining the train intervention effect on PA in participants with *high* vs *low baseline* scores (**Supplementary Figure 2A**) yielded a significant main effect of baseline score (F (1,14) = 8.02, $p < 0.05$, $\omega_p^2 = 0.31$), but no main effect of time (F (1,14) = 0.18, $p$ = 0.68) or baseline score × time interaction (F (1,14) = 1.63, $p$ = 0.22). The ANOVA results on NA (**Supplementary Figure 2B**) indicated a significant main effect of baseline score (F (1,16) = 25.47, $p < 0.001$, $\omega_p^2 = 0.58$), time (F (1,16) = 5.98, $p < 0.05$, $\omega_p^2 = 0.12$), and baseline score × time interaction (F (1,16) = 6.61, $p < 0.05$, $\omega_p^2 = 0.14$). This was due to a decrease of NA in the *high baseline* group only (mean difference of 4.0, $p < 0.01$; and 0.1, $p$ = 0.93 for the *high and low baseline* groups, respectively). In addition, the significant difference observed between the two groups at baseline (mean difference of 6.17, $p < 0.001$) was no longer significant after the intervention (mean difference of 2.1, $p$ = 0.13).

The ANOVA examining the music intervention effect on PA in *high vs low baseline* participants revealed a main effect of baseline score (**Supplementary Figure 2C)** (F (1,17) = 14.61, $p <$ 0.001, $\omega_p^2 = 0.42$) but no main effect of time (F (1,17) = 1.43, $p$ = 0.25) or baseline score × time interaction (F (1,17) = 0.24, $p$ = 0.63). The results of the ANOVA on NA showed (**Supplementary Figure 2D**) a main effect of baseline score (F (1,17) = 20.73, $p <$ 0.001, $\omega_p^2 = 0.51$), but no main effect of time (F (1,17) = 0.087, $p$ = 0.77) or baseline score × time interaction (F (1,17) = 0.035, $p$ = 0.85).

In the control group, there was a main effect of baseline score (F (1,17) = 37.4, $p < 0.0001$, $\omega_p^2 = 0.31$) for PA, but no main effect of time (F (1,17) = 0.26, $p$ = 0.61) or baseline score × time interaction (F (1,17) = 3.24, $p$ = 0.09) (**Supplementary Figure 2E**), as expected. Similarly, the ANOVA on NA in the control group yielded no significant main effect of baseline score (F (1,17) = 6.9, $p < 0.05$, $\omega_p^2 = 0.31$), time (F (1,17) = 0.30, $p$ = 0.59); or baseline score × time interaction (F (1,17) = 0.10, $p$ = 0.76) (**Supplementary Figure 2F**).

## Cognitive Measures

When assessing the effect of the train intervention on WM task 1 (**Figure 3A**), the ANOVA revealed no significant main effect of group (F (1,36) = 4.13, $p$ = 0.05), or time (F (1,36) = 1.05, $p$ = 0.31), but a significant interaction (F (1,36) = 9.44, $p < 0.01$; $\omega_p^2 = 0.06$). Post-hoc tests revealed a significant mean post-pre change score in the intervention group (mean change = 0.63, $p < 0.001$) that was absent in controls (mean change = -0.32, $p$ = 0.16). For WM task 2, the ANOVA yielded no main effect of group (F (1,36) = 0.12, $p$ = 0.73), or time (F (1,36) = 0.59, $p$ = 0.45), but a significant interaction (F (1,36) = 8.27, $p < 0.01$; $\omega_p^2 = 0.08$) (**Figure 3B**). Pairwise comparisons show that the mean post-pre change score was significant in the intervention group (mean change = 2.0, $p <$ 0.05), but not in the control group (mean change = -1.16, $p$ = 0.16). No significant main effects or interactions were observed for WM tasks 3 (**Figure 3C**) and 4, and attention tasks one and 2. However, a significant main effect of time (F (1,36) = 4.56, $p < 0.05$; $\omega_p^2$ = 0.06) was found on attention task two scores (**Supplementary Table S2**).

The ANOVA examining the music intervention effect on WM task 1 (**Figure 3D**) indicated no main effect of group (F (1,36) = 0.95, $p$ = 0.34), or time (F (1,36) = 0.03, $p$ = 0.86), but a significant interaction (F (1,36) = 5.24, $p < 0.05$; $\omega_p^2 = 0.03$). Post hoc tests indicated that the mean post-pre change score was not significant

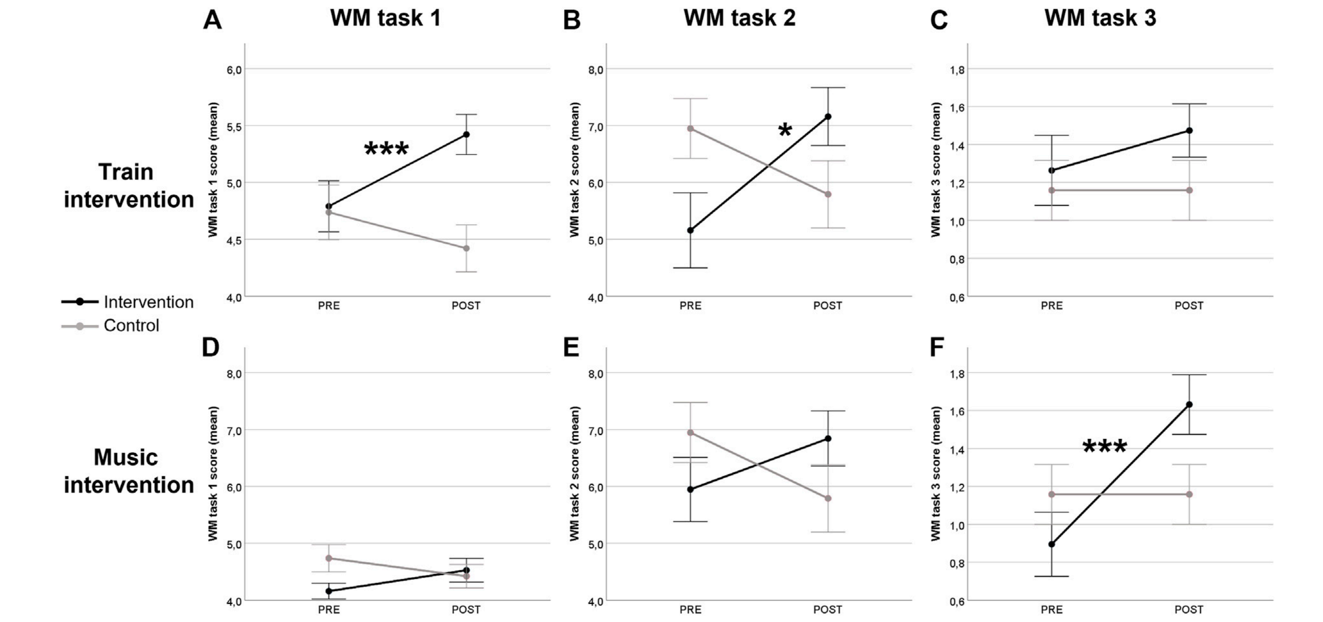


**FIGURE 3 |** Pre- and post-intervention scores in working memory tasks 1, two and 3. Mean score (±SEM) on the working memory task 1 **(A–D)**, 2 **(B–E)** and 3 **(C–F)** before (PRE) and after (POST) the train and the music intervention in comparison to the control condition. POST, post-intervention; PRE, pre-intervention; WM, Working Memory; #*p* < 0.05 and ##*p* < 0.01 for post-hoc tests comparing pre-vs post-intervention scores when interaction was significant.

in both intervention and control groups (Music: mean change = 0.37, $p = 0.09$; Ctrl: mean change = -0.32, $p = 0.14$). The ANOVA on WM task 2 (**Figure 3E**) revealed no main effect of group, (F (1,36) = 0.002, $p = 97$, or time, F (1,36) = 0.08, $p = 0.77$), but a significant interaction (F (1,36) = 5.03, $p < 0.01$; $\omega_p^2 = 0.04$). Pairwise comparisons showed no significant mean post-pre change score in both intervention and control groups (Music: mean change = 0.89, $p = 0.17$; Ctrl: mean change = -1.16, $p = 0.08$). The ANOVA on WM task 3 (**Figure 3F**) yielded no significant main effect of group (F (1,36) = 0.28, $p = 0.60$) or time, F (1,36) = 11.84, $p < 0.01$), but a significant interaction (F (1,36) = 11.84, $p < 0.01$; $\omega_p^2 = 0.06$). Post hoc tests revealed that the mean post-pre change score was significant in the intervention group (mean change = 0.74; $p < 0.0001$) while it was absent in controls (mean change = 0.00; $p = 1.00$). No significant main effects or interactions were observed when analyzing the influence of the music intervention on WM task 4, and attention tasks one and 2 (**Supplementary Table S3**).

## DISCUSSION

To our knowledge, this is the first study to address the tolerability and user experience of fully immersive VEs aimed at improving emotional state and cognition in individuals with SCD. Our first goal was to measure cybersickness and user experience. Our results indicate that participants appreciated and tolerated both train and music VEs well. Our second goal was to assess the impact of each intervention on self-reported emotion and objective measures of WM and attention. NA decreased following the train intervention in participants reporting a high level of NA at baseline. Interestingly, preliminary results indicated that WM may benefit from both interventions, but not attention.

While interventions using VR have gained momentum (Kim et al., 2019), only a few feasibility studies have been conducted in populations of older adults (Manera et al., 2016; Ouellet et al., 2018; Corriveau Lecavalier et al., 2020). Feasibility studies are important to ensure that an effective intervention will be tolerated, appreciated and accepted, and therefore useful to the target population. Here, we extend results from previous studies by showing that older adults with SCD, who are at risk of dementia, did not experience cybersickness symptoms following brief exposure to fully immersive VR.

User experience is a critical element to determine future use of the technology and to guide developers, who can adapt applications to provide the best experience for end users (Law, 2011). This is especially true for older adults, who are not as experienced with technology as younger people and will adopt it only when it is adapted to their capabilities (Proctor et al., 2011; Holthe et al., 2018). Here, participants positively perceived the hedonic quality (i.e., quality aspects not directly related to functionalities) of both VEs, perceiving them positively for the following: *creativity*, *novelty*, *professionalism*, *stylishness* and *presentability*. Attractivity (i.e., level of appeal) was also perceived positively in both VEs. The music environment was considered highly *likable*, *inviting, good, appealing and motivating*. However, there were some word-pairs that were seen as neutral: *technical/human, unpredictable/predictable, favouring isolation/connection* and *separates me from people/ brings me closer to other people*. As these characteristics are inherent to VR technology (i.e., VR is a technology and being immersed in a VE separates the user from others), neutral values should not be interpreted as reflecting a non-satisfactory user experience. Instead, this suggests that our VEs have a good ecological value as this purely technical experience was rated as equally technical and human. Nevertheless, these impersonality factors must be carefully examined for future applications in people who may be more sensitive to these factors, such as individuals with affective or social disorders.

No pre-post intervention effect on self-reported affect was observed when examining the whole group of participants. However, a decrease in NA was detected following the train intervention in participants who had reported a higher NA score at baseline. This is aligned with previous results indicating decreased frustration measured with EEG markers (Abdessalem et al., 2020). Surprisingly, the music intervention personalized with the intelligent agent did not improve PA or NA. EEG analyses may possibly provide more sensitive measures of negative emotions (Byrns et al., 2020). Future studies will need to assess these variables further with a larger sample size.

In addition to the effects on emotions, both interventions induced a small improvement in WM compared to the control group. WM is a cognitive function that decreases greatly with age (Saba and Blanchet, 2020) and has been found to be sensitive to emotional variability (Garrison and Schmeichel, 2019). This indicates that WM may benefit from VR interventions rather than being due to a practice effect. This effect was not observed consistently across the different tasks and interventions for reasons that cannot be fully understood, given the differences between the two studies and the small sample size (Abdessalem et al., 2020; Byrns et al., 2020). Regardless, these results are in accordance with previous studies indicating that emotional states are linked to cognitive processes, such as WM (Williams et al., 1996; Blair et al., 2007; Verbruggen and De Houwer, 2007; Conway et al., 2013; Su et al., 2017; Garrison and Schmeichel, 2019).

There are some limitations to this study. First, as this was designed as a feasibility and proof-of-concept study, our sample size was small, and the study was not designed to assess efficacy. Given these encouraging results, we plan to conduct a larger-scale study to confirm them. Second, this is not a fully balanced design: There was no intelligent agent presented in the train intervention because its primary goal was to assess whether a travel environment was well-tolerated and reduced negative emotions. Lastly, we only tested older adults with SCD, and it would be interesting to address the same questions in older adults with cognitive impairments and/or neuropsychiatric symptoms. These populations could greatly benefit from such interventions contributing to well-being.

In conclusion, this feasibility study successfully showed that VR interventions are well-tolerated and appreciated, and may induce beneficial changes in emotional states and improvements in cognition. This study opens the way to the completion of a larger-scale study focusing on the interventions' efficacy.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Board (REB) vieillissement-neuroimagerie of the CIUSSS-CSMTL. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

MC, HBA, M-AB, AB, CF, and SB participated in the conceptualization of the study and design. MC wrote the first version of the manuscript. SB revised and contributed to the writing of the first version. All authors carefully revised the final manuscript and accepted the final submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2021.807991/full#supplementary-material

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# Because I'm Happy—An Overview on Fostering Positive Emotions Through Virtual Reality

*Katarina Pavic* [1,2,3]*, *Dorine Vergilino-Perez* [1], *Thierry Gricourt* [3] *and Laurence Chaby* [4,2]

[1]*Université de Paris, Vision Action Cognition, Paris, France,* [2]*Sorbonne Université, CNRS, Institut des Systèmes Intelligents et de Robotique, ISIR, Paris, France,* [3]*SocialDream, Research and Development Department, Bourg-de-Péage, France,* [4]*Université de Paris, UFR de Psychologie, Boulogne-Billancourt, France*

In recent years, an increased demand for improving mental health and well-being led to developing procedures capable of enhancing positive experiences. One highly attractive candidate for evoking positive experiences is Virtual Reality (VR), as VR enables users to experience various situations in controlled and safe environments. This overview first investigates how positive emotions, well-being and VR are interconnected. Then, an overview about how and why to induce positive emotions in adult users is provided. Methodological and ethical considerations about VR technology, measurements of VR's efficacy and user characteristics are reviewed. It emerges that VR is efficient in inducing positive emotions across the adult lifespan and in various settings. Levels of immersion, interactivity, Virtual environment contents, sensory modalities involved and users' characteristics emerged as key determinants for successfully inducing positive emotions with VR. The main applications of positive VR experiences consist in using VR for relaxation, stress and pain management, motivation for physical activities, and gives promising results for apathy treatment in elderly users. Although VR is efficient in eliciting positive emotions and experiences, the underlying operating mechanisms remain unclear and are yet to be further investigated. Finally, the need for a user-centered approach when designing positive VR experiences, clear guidelines for the use of VR, and a better documentation of its potential adverse effects are addressed.

**Keywords: virtual reality, well-being, aging, mood induction, emotion, physiological measure, positive technologies**



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***Correspondence:**
*Katarina Pavic*
*katarina.pavic@u-paris.fr*

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## 1 INTRODUCTION

### 1.1 From Positive Emotions to Well-Being

Taking a stroll in nature, sharing pleasant moments with relatives or friends, traveling and discovering new places. While all these experiences may seem trivial, they are beneficial for our well-being, thanks to the positive emotions that can emanate from them. A large body of literature showed that positive emotions are the founding stone of human fulfillment and well-being (Fredrickson and Joiner, 2002; Fredrickson, 2004; Fredrickson, 2006; Garland et al., 2010). In addition, positive emotions are closely associated with quality of life (Kuppens et al., 2008), life success (Lyubomirsky et al., 2005), better health and longevity (Diener and Chan, 2011) and cognitive functioning (Dolan, 2002; Blair et al., 2007). Therefore, there are clear benefits in promoting positive experiences and emotions among healthy, vulnerable and/or isolated adults. Despite the high benefits of positive emotions emanating from the above-mentioned experiences, not everyone has regular access to nature walks, social interactions or travel. Moreover, access has become even more restricted due to the current COVID-19 crisis, leading to heightened mental health issues (Ganesan et al., 2021), increased loneliness and isolation (Killgore et al., 2020). A critical concern that needs to be addressed is how people can have access to positive experiences for enhancing well-being and mental health. One innovative answer for bringing nature, people and places together may be virtual reality (VR). VR has the advantage of enabling users to safely experience various real-life or imaginary situations, while allowing tight control over the stimuli used (Baños et al., 2017; Freeman et al., 2017). VR is therefore a suitable candidate for promoting positive experiences.

Historically, research has focused on understanding negative emotions and pathology, while positive emotions, well-being and the links between them have been understudied (Alexander et al., 2020). In recent years, considerable efforts have been made to delimit and describe the diversity of positive emotions, revealing that positive emotions are more than the mere concepts of "joy" and "happiness" (see Desmet, 2012; Alexander et al., 2020). In this context, the broaden-and-build theory provides a framework for understanding the links between positive emotions, cognition and well-being (Fredrickson, 2004; Fredrickson, 2006). According to this theory, positive emotions broaden one's mind, unlike negative emotions that lead to narrowing one's mind (Garland et al., 2010; Cohen et al., 2016). This has been supported by studies reporting attentional capture and broadening following positive emotion induction (Fredrickson and Branigan, 2005; Gupta, 2019). In return, the mind broadening resulting from positive emotions helps build long-lasting resources, such as social connections, opportunities and knowledge, resulting in well-being (Fredrickson, 2004; Fredrickson, 2006; Garland et al., 2010). Enhancing positive emotion and accumulating long-lasting resources may be of great interest in vulnerable and/or isolated populations such as elderly people (Ong, 2010). Additionally, it has been argued that positive emotions are linked to better health outcomes and longevity (Diener and Chan, 2011). Therefore, gaining a better understanding of positive emotions appears as crucial as understanding and relieving negative ones.

Growing interest in positive emotions and their potential links to individuals' well-being began with the development of positive psychology, a scientific field that investigates well-being at the individual, organizational and societal levels (Seligman and Csikszentmihalyi, 2000). This has led to a paradigm shift where well-being is no longer seen as the absence of health issues, but also as the presence of positive emotions, resources, and strengths (Seligman and Csikszentmihalyi, 2000; Bos et al., 2016). Defining the notion of well-being is not straightforward, since in the existing literature, the terms "well-being," "happiness" and "life satisfaction" are often used interchangeably (Suardi et al., 2016). However, two main approaches can be identified in the literature: 1) subjective and 2) psychological well-being. Subjective well-being, or "hedonia," consists in life satisfaction, with a focus on positive, pleasant experiences and quality of life (Diener et al., 1999). Psychological well-being, also called "eudaimonia," focuses on long-term fulfillment, encompassing the idea of constant improvement towards fulfilling life-goals and optimal functioning (Ryff, 1989; Lent, 2004). As these two major approaches have overlapping goals and are not fully exclusive, integrative theories of well-being have developed (e.g., see Henderson and Knight, 2012) in parallel to critics suggesting they are two sides of the same coin (e.g., see Kashdan et al., 2008).

## 1.2 Fostering Positive Emotions Through Technology

Recently, technologies have become believable candidates for enhancing individuals' health and well-being, leading to the emergence of "positive technologies". Derived from positive psychology, the positive technologies framework investigates the use of technology to improve users' well-being, quality of life and experiences (Botella et al., 2012; Riva et al., 2012; Baños et al., 2017). It has been suggested that positive technologies can enhance subjective ("hedonia"), psychological ("eudaimonia") or social well-being (Botella et al., 2012; Riva et al., 2012; Baños et al., 2017). VR belongs to the technologies cited within the framework of positive technologies, especially as a "hedonic" technology enabling positive and pleasant experiences in the present (Botella et al., 2012; Riva et al., 2012). What makes VR a suitable candidate for fostering positive experiences are its immersive power and the sense of presence that VR experiences generate. Historically, sense of presence has been defined as the feeling of "being physically there" (i.e., spatial presence, Slater, 1999; Steuer, 1992) to which can be added the feeling of "being with others" (i.e., social presence, Biocca et al., 2001).

Recent research has established that VR is arousing (Felnhofer et al., 2015; Marín-Morales et al., 2018) and is an effective tool for inducing emotions in laboratory settings (Bernardo et al., 2021). More precisely, VR has proven effective in inducing various positive emotions, such as joy, relaxation (e.g., see Anderson et al., 2017; Serrano et al., 2016) and more complex emotions such as awe (i.e., feeling of wonder when confronted with vast and transcending stimuli, Chirico et al., 2017; Chirico et al., 2018) and the sublime (i.e., feeling of "amazement tinged with fear" in response to vast or powerful stimuli, Chirico et al., 2021). However, significant divergences can be observed about recruited users and the material used for inducing positive emotions with VR. As these methodological choices can greatly influence the emotions induced, they will be further examined in the present article.

## 1.3 Aim of the Overview

There are already reviews about VR, emotion induction, well-being and their links to mental health. A recent systematic review confirmed that VR technology is efficient for inducing both positive and negative emotions in lab-settings (Bernardo et al., 2021). Other reviews highlighted VR's potential for improving mental health (Freeman et al., 2017; Jerdan et al., 2018), and elder's quality of life and emotions (D'Cunha et al., 2019; Kim et al., 2019). However, the aim of these reviews was not about understanding key aspects that need to be considered when inducing positive emotions with VR across the adult-life span.

Additionally, VR interventions for mental health mostly relied on exposing participants to negative stimuli, for example in the context of exposure therapies, craving induction, or better understanding paranoia among else (Freeman et al., 2017; Jerdan et al., 2018).

Thus, the goal of the present article is to provide an overview and reflect on key determinants for inducing efficiently and safely positive emotions with VR technology. We specifically aim to survey the methodology used for inducing positive emotions, as well as address theoretical and ethical considerations that need to be taken into account. The following topics will be covered in the subsequent sections:

- How and why to induce positive emotions in healthy adult users;
- Can positive emotion induction through VR be beneficial for elderly users;
- What are the potential underlying cognitive mechanisms involved during positive emotion induction with VR.

## 1.4 Scope and Limitations

There are several definitions of VR in the literature, focusing rather on its immersive (e.g., Slater and Wilbur, 1997) or interactive (e.g., Steuer, 1992) proprieties. For present purposes, VR will be defined as "inducing targeted behavior in an organism by using artificial sensory stimulation, while the organism has little or no awareness of the interference" (LaValle, 2016). While this is a broad definition, it has the advantage of including varying levels of immersion (LaValle, 2016), ranging from low immersive and more affordable devices such as screens, to highly immersive Cave Automated Virtual Environments, whereby users enter a room with graphical projections onto surrounding walls (Cruz-Neira et al., 1993), and Head-Mounted Displays (HMDs). We decided to include a broad range of devices in order to investigate the degree of immersion and/or interactivity needed for an optimal emotion induction through VR, therefore not limiting the present survey to highly immersive devices such as CAVEs and HMDs. However, as VR technology has been in constant development the last few years it is more than possible that methodological, theoretical and ethical aspects discussed in this paper are prone to change in the future (Elor and Kurniawan, 2020).

Inducing positive emotions through VR implies using it as a Mood Induction Procedure (MIP). MIPs are well-established experimental procedures for inducing temporary emotional states, considered similar to the ones experienced in everyday life (Martin, 1990; Baños et al., 2012). MIPs relies traditionally on presenting arousing pictures (Lang et al., 1997), film sequences (Gross and Levenson, 1995), music (Västfjäll, 2001) or sentences (Velten, 1968). However, a caveat about MIPs must be addressed, as "emotion" and "mood" are often used interchangeably, making it unclear what is truly induced via these procedures. For the sake of clarity and to ensure consistency throughout this overview, "emotions" will be defined as states elicited by precise events or stimuli, and of short duration (Scherer, 2005). Following Sander et al. (2005), emotions will be considered to consist of the following five components: subjective feeling, stimulus evaluation, motivation, motor expression and physiological responses. In contrast, "mood" consists of broader and more diffuse states, and does not necessarily need a contextual stimulus (Ekkekakis, 2012).

We believe that this work will be of interest to researchers in affective cognitive sciences, psychologists, and healthcare providers wondering which material and content to use, and why it is relevant to induce positive emotions in adults users. For a broad picture of this overview, we have presented a Sankey Diagram (**Figure 1**) based on studies included in this overview. The Sankey Diagram allows a quantitative visualization and understanding of the links between recruited populations, employed VR devices, VE contents, affective measures and study aims. The details about each study included in the diagram can be found in **Supplementary Material**.

# 2 Fostering Positive Emotions Among Healthy Young Users

## 2.1 How to Induce Positive Emotions Through VR?

Pivotal studies in the field of positive emotion induction through VR have been conducted on healthy young adults, usually students, to confirm whether it is possible to induce positive emotions with VR (Riva et al., 2007; Baños et al., 2008) and whether the technology employed is acceptable and useful (Baños et al., 2014). Since then, a large body of literature explored which methodological aspects can greatly influence users' experience (see **Supplementary Table S1**). It appears that the level of immersion, interactivity, VE contents, and sensory modalities involved are key determinants for fostering positive emotions. As there are discrepancies in the affective measures used to assess VR's efficacy for inducing positive emotions, they will also be covered in the present section.

Ensuring that VR technology is adequately tolerated by healthy young users is the prerequisite before aiming to induce positive emotion. Cybersickness corresponds to adverse effects during and after VR exposure, and is characterized mainly by symptoms such as eye strain, headaches, sweating, disorientation, and nausea (LaViola, 2000). It is usually assessed by the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993). Intriguingly, only three studies inducing positive emotions with HMDs have explicitly assessed cybersickness symptoms (Bittner et al., 2018; Liszio and Masuch, 2019; Seabrook et al., 2020). However, the results of these studies corroborate good tolerance of HMDs in the context of positive emotion induction (Bittner et al., 2018; Liszio and Masuch, 2019; Seabrook et al., 2020).

The first aspect that needs to be taken into account when inducing positive emotions with VR is the level of immersion. There is a heterogeneity of devices included under the umbrella term VR in the literature, and with varying levels of immersion that can lead to low or more intense emotional states (Visch et al., 2010; Diemer et al., 2015). Surprisingly, a limited number of studies have compared immersion levels needed for positive emotion induction. One study compared the effectiveness of inducing positive emotions using an HMD, a tablet, or reading neutral text (control condition) (Bittner et al., 2018). Although

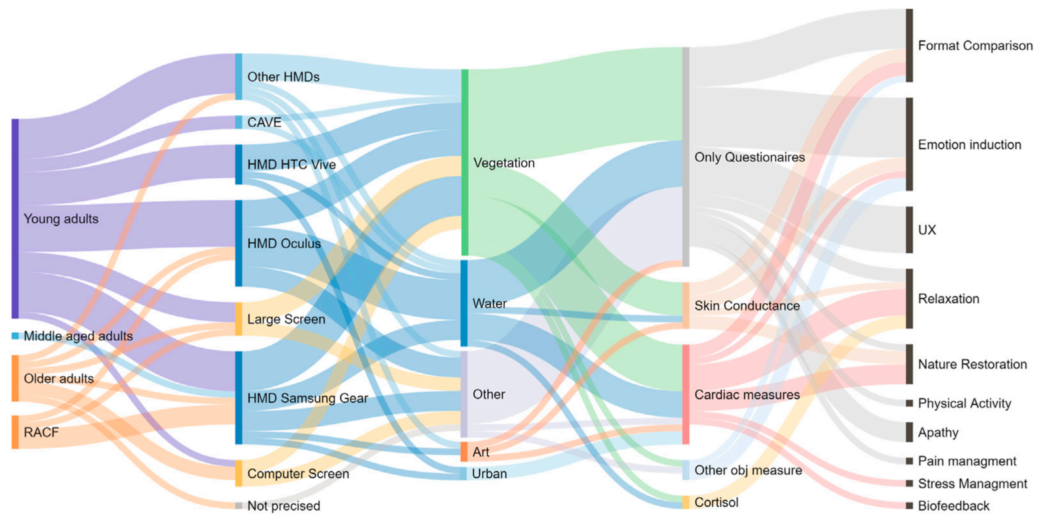


**FIGURE 1 |** Sankey diagram illustrating links in the literature between recruited populations, VR devices, VE contents, emotional measures and study aims in the field of fostering positive emotions through VR. For instance, the majority of the studies recruited young adults in their study, and the majority of studies that recruited participants in RACFs used a Samsung Gear HMD. Stroke breadths indicate the number of experiments for a given category going from left to right. Abbreviations: RACF, Residential Aged Care Facility; HMD, Head-Mounted Display, obj, objective; UX, User Experience (in this case acceptability and/or feasibility studies).

VR was most effective in improving positive emotions and mild depressive symptoms, the superiority of the HMD over a less immersive tablet was slight (Bittner et al., 2018). A second study showed a superiority of HMD compared to a screen for inducing awe (Chirico et al., 2017), however, as awe is a complex emotion, it is difficult to conclude if this is true for basic positive emotions.

The second aspect that needs to be considered is the level of interactivity and user engagement within the VEs. Interactive VR experiences under a HMD appear to enhance positive emotions (Yeo et al., 2020), and reduce stress (subjective and physiological) (Liszio and Masuch, 2019) better than non-interactive VR experiences. Authors suggest that these results can be explained by the ability of interactive experiences to capture and hold users' attention over time (Yeo et al., 2020). Nevertheless, a consensus about what falls under the term of "interactive" is required, as it sometimes means accomplishing a task in the VE (Liszio and Masuch, 2019), or navigating freely in the VE (Yeo et al., 2020).

Third, contents of the VEs have to be considered, as they can greatly influence induced emotions (Gross and Levenson, 1995). Most of the studies involved natural settings featuring either vegetation or water (see **Figure 1**). This is in line with well known and documented benefits of natural environments on emotions (for a review see McMahan and Estes, 2015). Several studies confirmed that exposure to virtual nature increases positive emotions and/or perceived restoration (Riva et al., 2007; Browning et al., 2020; Mattila et al., 2020; Seabrook et al., 2020; Yeo et al., 2020) while also significantly reducing negative ones (Villani and Riva, 2012; Anderson et al., 2017; Yeo et al., 2020). Additionally, virtual nature has a positive impact on physiological arousal, further confirming its relaxing and restorative properties (Annerstedt et al., 2013; Anderson et al., 2017; Browning et al., 2020). Similar benefits of real and virtual nature have been observed when using highly-immersive HMDs (Chirico and Gaggioli, 2019; Browning et al., 2020). There are however discrepancies on the best way to deliver virtual nature experiences, as it has been reported similar benefits of computer-generated and 360°natural videos (Brivio et al., 2021), or greater efficacy of computer-generated VEs (Yeo et al., 2020) in inducing positive emotions.

Fewer studies have investigated the effect of other types of VE contents such as art (Valtchanov et al., 2010; Chirico et al., 2021), crowded urban environments (Yu et al., 2018), or personalized VE contents (Evans et al., 2020). Art and urban-based contents have usually been compared to virtual nature's efficacy for inducing positive emotions. It emerged a superiority of natural VE contents for inducing the sublime (Chirico et al., 2021), as well as heightened positive emotions and resource restoration compared to virtual art (Valtchanov et al., 2010). Furthermore, compared to crowded urban environments, natural environments again induced greater positive emotions and vigor in young adults (Yu et al., 2018). However, studies comparing urban and natural environments in VR did not manage to show physiological changes or differences between natural and urban environments. Finally, personalized 360° videos also appeared as efficient for inducing positive emotions (Evans et al., 2020), although their efficacy has not been compared to other VE contents.

The fourth key determinant that needs to be considered is the sensory modality involved in positive VR experiences. Only one study investigated the influence stereoscopy, i.e., the presentation of a different image to each eye in order to give an impression of depth, revealing that it does not impact the valence or intensity of induced emotions (Baños et al., 2008). Furthermore, it is preferable to include auditory stimuli, rather than relying solely on visual stimuli (Annerstedt et al., 2013; Kern et al., 2020). Auditory stimuli mostly consisted in music and/or ambient environmental sounds (e.g., birds chirping, waves, etc.), and on fewer occasions on positive narratives (e.g., Riva et al., 2007; Seabrook et al., 2020). The added value of olfactory and tactile stimulation have been explored in one study, concluding that auditory and visual information were sufficient in VR for relaxing participants (Serrano et al., 2016).

Finally, VR's efficacy for inducing targeted emotions has mainly been investigated with questionnaires, the most widely used ones being the Positive and Negative Affect Schedule (Watson et al., 1988) and Visual Analogical Scales (VAS, see Baños et al., 2012). More recently, physiological measures have started to be collected in addition to questionnaires, confirming VR's capacity for arousal (Felnhofer et al., 2015). Commonly collected physiological measures are skin conductance, and cardiac measures such as Heart Rate (HR) or Heart Rate Variability (HRV) (see **Figure 1**). In a limited number of studies, electromyography (Chirico et al., 2017), cortisol (Annerstedt et al., 2013; Liszio et al., 2018) or electroencephalography (Marín-Morales et al., 2018) have been used to explore VR's potential for inducing emotions.

## 2.2 Why Induce Positive Emotions in Healthy Users?

Positive emotions coupled with VR can have great benefits on healthy users' physical activity. For instance, when combined with stationary cycling, a virtual park inducing joy efficiently motivated users (Miragall et al., 2021). However, authors pointed out that inducing joy was not sufficient to increase user's motivation without an appropriate body posture (e.g., leaning forward posture while pedaling) (Miragall et al., 2021). It emerges that coupling VR, positive emotion induction and exercise can have great benefits on users' motivation, although VR and positive emotions by themselves are not sufficient for that goals. It should be noted that the present studies used large screens, possibly because using HMDs for exercise may be challenging and increase cybersickness symptoms.

There is also compelling evidence that VR experiences are efficient for relaxation when combined with VE contents showing natural settings. On numerous occasions, virtual nature (both vegetation and water features) has proven to be efficient for inducing relaxed states in healthy young adults (Riva et al., 2007; Annerstedt et al., 2013; Anderson et al., 2017; Browning et al., 2020; Mattila et al., 2020) and supporting mindfulness practice (Seabrook et al., 2020). Furthermore, it has been verified that the novelty and attractiveness of VR did not distract participants from accessing a relaxed yet focused state needed for biofeedback (Rockstroh et al., 2019) or hypnosis (Thompson et al., 2010). A recent study revealed that VR relaxation applications are overall positively perceived by users (Fagernäs et al., 2021), further confirming their usefulness.

One last application of positive emotions induced through VR among healthy young adults is stress and pain management. Inducing positive emotions with VR appears efficient at recovering from acute stress, with subjective outcomes such as improved self-report emotions, and objective outcomes such as an increased HRV (Villani and Riva, 2012; Annerstedt et al., 2013; Liszio and Masuch, 2019). Additionally, playing a game in an aquatic environment under an HMD has proven efficient in reducing experimentally induced pain (Gordon et al., 2011). However, VR was efficient in reducing only high intensity pain, and both HMDs and CAVE were efficient for accomplishing it (Gordon et al., 2011).

It should be noted that the vast majority of the above-mentioned studies used natural contents. This demonstrates the virtues of nature, while again confirming the need for investigating the potential benefits of social contents, notably for physical activity and motivation. For instance, it could be relevant to compare exercising in natural virtual environments and exercising with a virtual coach in order to better understand the influence of the contents on positive VR applications. Additionally, as the previously cited studies about positive emotion induction through VR and their applications were conducted on healthy young adults, their generalization to more vulnerable users needs to be addressed separately.

# 3 Towards Successful Aging With VR

Although the majority of VR studies on positive emotion induction have been conducted on young adults, a growing number of studies have investigated the use of VR for elderly users (see **Supplementary Table S2**). Fostering positive experiences can be particularly beneficial to elderly adults, given the previously discussed benefits of positive emotions on health and quality of life (Kuppens et al., 2008; Diener and Chan, 2011). Moreover, it is generally admitted that positive emotions and happiness follow a U-shaped pattern throughout the life-span, with an improvement from early to advanced adulthood (although see Steptoe et al., 2015). However, advancing in age is often described as a developmental process characterized by social, physical and cognitive losses (Baltes and Baltes, 1990; Baltes and Carstensen, 2003). In contrast, the concept of "successful aging" has emerged, consisting in aging with well-functioning physical and cognitive abilities, and minimized risks of developing diseases and disabilities (Rowe and Kahn, 1987; Rowe and Kahn, 2015). Thus, exploring positive VR experiences for elderly users has a twofold advantage, as it may enable a better understanding of why some people are considered to age successfully while also potentially alleviating age-related health issues and decline.

Providing elderly users with VR experiences requires ensuring that the VR devices and high levels of immersion are adapted to them. Elderly users seem to prefer devices with lower levels of immersion, such as smartphones, to highly-immersive HMDs, while the opposite holds for younger adults (Liu et al., 2020). On a similar note, hospitalized patients who were not interested in testing an HMD were older than those who were interested (Mosadeghi et al., 2016). This does not mean that older adults do not appreciate HMDs, as they usually find highly immersive VR experiences enjoyable, and have a rather positive attitude towards HMDs once they have tested them (Huygelier et al., 2019). Furthermore, high levels of acceptance and satisfaction have been reported towards HMDs and CAVE for VR, which can be safely used with elderly users considered "in good health" (Benoit et al., 2015; Huygelier et al., 2019; Chan et al., 2020) or having cognitive and/or physical impairments (Roberts et al., 2019; Appel et al., 2020; Brimelow et al., 2020). The duration of immersion under an HMD may last up to 20 minutes, with little to no adverse side effects (Appel et al., 2020).

In line with these results, several studies confirm VR's efficacy for inducing positive emotions (such as joy and relaxation) in healthy middle-aged (Yu et al., 2020), elderly users (Etchemendy et al., 2011; Baños et al., 2012; Liu et al., 2020; Yu et al., 2020), or among more vulnerable and/or dependent users (e.g., residents of Residential Aged Care Facilities, RACF) (Moyle et al., 2018; Roberts et al., 2019; Appel et al., 2020; Brimelow et al., 2020). As for younger users, most of the studies relied on natural-based VE contents (Baños et al., 2012; Moyle et al., 2018; Huygelier et al., 2019; Appel et al., 2020; Brimelow et al., 2020), mainly because of their well-known benefits and safety of use (Appel et al., 2020). Additionally, it has been showed that nature contents lead to lower feelings of tiredness and depression in middle-aged and older adults (Yu et al., 2020). Several studies used other VE contents such as interactive applications (Etchemendy et al., 2011; Baker et al., 2020) or personalized contents (Benoit et al., 2015), mainly in order to investigate elderly users' acceptability and satisfaction of these contents (see **Supplementary Material**).

Positive emotions induced through VR have proven to be useful in improving cognitive and physical outcomes in people with mild cognitive impairment (Kim et al., 2019) and people living with dementia (D'Cunha et al., 2019). A growing demand for using VR to reduce apathy in RACFs has also sprung up in recent years. Although current evidence is limited to exploratory and preliminary research, VR has potential for reducing apathy in addition to improving overall emotions (Brimelow et al., 2020). This observation is further supported by residents' families and by staff members (Moyle et al., 2018). However, one limitation is the lack of control groups in order to understand to what extent VR by itself is efficient in reducing apathy compared to traditional treatments. A research project aims at answering this limitation by including an active and passive control group for comparison with the VR group (Saredakis et al., 2020).

As a side note, despite high levels of satisfaction and an efficient induction of positive emotions, it has been reported on several occasions that VR also induces negative emotions in elderly users (Appel et al., 2020; Brimelow et al., 2020; Chan et al., 2020; Liu et al., 2020), especially feelings of anxiety or fear (Moyle et al., 2018). These mixed feelings about VR experiences can be explained by characteristics of the users and of the devices. It is plausible that VR experiences, especially those involving HMDs, are less appropriate for users with cognitive deficits, who may experience VR as confusing or even intrusive (Roberts et al., 2019; Baker et al., 2020). Elderly users have reported the following drawbacks of VR experiences: physical discomfort and blurred vision due to inadequate devices, issues for executing required movements in VE, worries about using the equipment without assistance, and personal preference for less immersive experiences (Roberts et al., 2019; Baker et al., 2020; Liu et al., 2020).

# 4 DISCUSSION

## 4.1 Strengths and Weaknesses of Positive Emotion Induction Through VR

In recent years increased interest in using technology to enhance health and well-being has sprung up (Kitson et al., 2018). The present review aimed specifically at investigating VR's potential for eliciting and fostering positive emotional states. This investigation was conducted on studies that recruited adult users, most of them conducted on young healthy users. It emerged that VR is a safe and potent technology for inducing positive emotions in young and elderly users. The results of the present overview support the claim that the positive emotions induced through VR provide effective leverage for physical activity (Miragall et al., 2021), alleviating induced stress (Annerstedt et al., 2013; Liszio and Masuch, 2019) or pain (Gordon et al., 2011) in healthy young adults, as well as a promising tool for reducing apathy in elderly users (Moyle et al., 2018; Brimelow et al., 2020).

High levels of acceptability, satisfaction and perceived usefulness of positive VR experiences have been reported by young adults, and elderly users. However, a limited number of studies assessed explicitly VR tolerance and cybersickness symptoms when inducing positive emotions. As variable levels of cybersickness symptoms have been reported in the literature, with usually women (Stanney et al., 2020), and elderly users (Arns and Cerney, 2005; Huygelier et al., 2019) being more prone to it, generalizing explicit measures of cybersickness symptoms appears relevant, especially when aiming to induce positive emotions. Employing objective measures in addition to self-reported measures of cybersickness could also be relevant for a better detection of cybersickness symptoms (see Chang et al., 2020).

There are no clear answers about the levels of immersion and interactivity required for inducing positive emotions. Although highly immersive HMDs and CAVE are particularly efficient for inducing positive emotions (Chirico et al., 2017; Chirico et al., 2018; Browning et al., 2020), alleviating negative emotions (Bittner et al., 2018) and sensations (Gordon et al., 2011), their superiority to screens remains to be validated. Moreover, interactivity appears beneficial for inducing positive emotions (Villani and Riva, 2012; Liszio and Masuch, 2019) and preventing users' boredom (Yeo et al., 2020), yet the majority of the studies relied on non-interactive VR experiences. Additionally, low immersive devices and non-interactive VR experiences appeared efficient at conveying positive emotions, especially in elderly users. Further studies are needed to disentangle the optimal levels of immersion and interactivity required based on users' characteristics for fostering positive emotions.

Regarding VE contents employed for inducing positive emotions, it emerged that VEs of nature, i.e., vegetation and aquatic contents are widespread. This is mainly due to nature's health benefits (Twohig-Bennett and Jones, 2018), positive emotion improvement (McMahan and Estes, 2015) and ability to restore resources (Kaplan and Kaplan, 1989; Ulrich et al., 1991). However, several points need to be addressed about natural VE contents. Firstly, a neutral VE has not been systematically used for comparison, therefore making it difficult to fully state natural VE superiority for conveying positive emotions over other types of VE. Furthermore, a new research field consisting in using natural VE for promoting climate change awareness has started developing (Fauville et al., 2020). Natural VE are therefore employed for encouraging conservation behavior (Hsu et al., 2018; Nelson et al., 2020; Hofman et al., 2021), learning about ocean acidification (Markowitz et al., 2018) or visualizing a forest under climate changes (Huang et al., 2021). These natural VE do not necessarily aim at inducing positive emotions, but rather raising awareness which can lead to negative emotion induction (Hsu et al., 2018; Nelson et al., 2020). This means that natural VE are not intrinsically positive (or negative), but rather that their emotional valence relies heavily on the context and the meaning users are willing to give them.

Social contents may also present advantages for fostering positive emotions, yet they have been understudied. This is intriguing given that their use in VR could help to enhance social well-being, as argued within the positive technologies' framework (Botella et al., 2012; Riva et al., 2012; Baños et al., 2017). A research asking participants to record their personalized 360° video revealed that more than half of the participants' videos included family members, friends or loved ones, and that the majority of videos involved the presence of at least one person (Evans et al., 2020). Moreover, it emerged from studies investigating elderly users' preferences that they are particularly willing in using VR for social purposes and interactions (Roberts et al., 2019; Baker et al., 2020). This is in line with researches showing that social contents (i.e., with people present in the pictures/videos) induce greater subjective feelings of positive emotions (Colden et al., 2008), and different physiological responses to non-social contents (Britton et al., 2006). This may for instance explain why studies comparing "natural" and "urban" (therefore social) VE contents (Yu et al., 2018; Yu et al., 2020) failed to reveal clear physiological differences between the two types of content. Developing a database of various VE contents for emotion induction thus appears necessary, and there have been attempts for developing one (e.g., see Li et al., 2017).

VR's efficacy has mostly been investigated with questionnaires reporting "subjective" feelings, although in recent years they started being coupled to more "objective" measures, mainly skin conductance and various cardiac measures. As a matter of fact, it has been argued by various authors that combining questionnaires with "objective" measures helps better understand to what extent VR interventions are effective, and ensuring that participants do not simply experience social desirability-bias (Appel et al., 2020; D'Cunha et al., 2019; Felnhofer et al., 2015; Riva et al., 2007; Bernardo et al., 2021). However, a consensus about the relevant measures and the best way to collect them is needed since considerable heterogeneity was observed regarding the selected measures, the moment and duration of their collection.

More recently, there has been a growing interest in providing VR experiences, especially positive ones, to older users. When proposing positive VR experiences to elderly users, one should have the following considerations in mind. Depending on users' characteristics and preferences, lower immersive devices may be more suitable, especially when setting up VR interventions for users with cognitive and/or physical impairments, and the benefits of interactivity has yet to be investigated among elderly users. Nevertheless, it has been argued on several occasions that elderly users can find highly immersive CAVEs and HMDs enjoyable and draw benefits from them (Benoit et al., 2015; Huygelier et al., 2019; Appel et al., 2020). Constructors of positive VR experiences under HMDs could consider that their use may be compromised when users rely on hearing and/or visual aid devices (Roberts et al., 2019; Liu et al., 2020); should consider adapting the movements and inputs to be controller-free (Pimentel et al., 2021) and simplify the equipment and interfaces for novice and less autonomous users (Roberts et al., 2019). Lastly, further studies are necessary on middle-aged users, as so far only one study recruited these users (Yu et al., 2020), therefore it is not possible to conclude on VR's efficacy in these users.

Finally, several limitations must be addressed regarding studies that attempt to induce positive emotions through VR. Studies' sample sizes can range from 5 to over a thousand participants per study and experimental condition (see **Supplementary Material**). Smaller sample sizes have been observed in studies recruiting elderly users in RACFs and impairments, which implies lower statistical power (Akobeng, 2016). Additionally, effect sizes have not been consistently reported in presently selected studies, making it complex to fully conclude on VR's capacity for inducing positive emotions. However, a considerable number of studies with young adults reported medium to large effect sizes (see **Supplementary Material**) suggesting that VR is at least to some extent efficient for inducing emotions in younger users. More robust studies reporting effect sizes of positive VR interventions are needed to support its efficacy in middle-aged and elderly users. One should have also in mind the possibility of $p$-hacking, which consists in a set of questionable practices forcing results to be significant even in under-powered studies (Nelson et al., 2018; Botella and Suero, 2020). Lastly, a potential publication bias should be addressed, as the majority of the studies reported significant positive outcomes, while null or negative effects are a minority or non-existing so far in the literature. These statistical and publishing biases can be overcome by carefully reporting sample size measurements (Nelson et al., 2018), significant and non-significant results (Lakens and Etz, 2017), and studies pre-registration and/or replication (Nosek and Lakens, 2014).

## 4.2 Potential Cognitive Mechanisms Involved

While there is no clear explanation of why VR is so efficient in inducing positive emotions nor what its short and long term benefits are (Kenwright, 2018; Bernardo et al., 2021), findings allow us to speculate on the possible operating mechanisms. The **Figure 2** provides a visual illustration of the cognitive mechanisms covered in the present section, which investigates the links behind VR technology, positive emotions and users' characteristics.

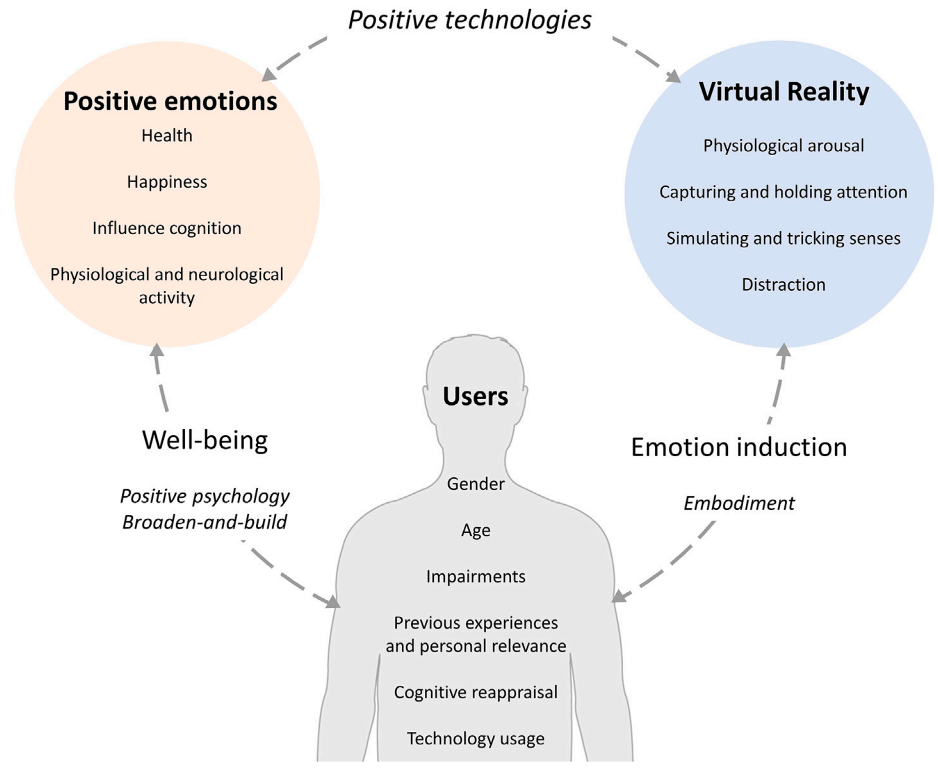


**FIGURE 2 |** A schematic illustration of potential cognitive mechanisms linking positive emotions, VR and users. Concepts written on the arrows describe the link between two instances, and the theoretical models explaining the existing link are written below in italics.

It has been argued that highly immersive VR is arousing (Visch et al., 2010; Chirico et al., 2017), able to capture and hold users' attention (Cho et al., 2002; Li et al., 2020; Seabrook et al., 2020), trick their senses (Gallace et al., 2012; Serino et al., 2016; Droit-Volet et al., 2020), as well as distract from negative affects and sensations (Malloy and Milling, 2010; Sharar et al., 2016). However, a neurological perspective on VR's benefits and adverse effects is highly needed. Recently, it has been suggested that VR and the brain may share similarities, i.e. embodied simulations (Riva et al., 2018). For the brain, embodied simulations imply the existence of a "body matrix," involved in coding visual, tactile and proprioceptive information which allows an individual to maintain a mental model of the body and the space around it (Moseley et al., 2012; Riva et al., 2018). Through the integration of several sensory stimuli, the body matrix is able to provide predictions about future actions (Riva et al., 2018). As VR shares the same characteristics of integrating several sensory inputs and predicting future user actions for optimal VR experiences, it has been suggested that VR can be considered as an "embodied technology" (Riva et al., 2018; Yu et al., 2020). Currently, VR is highly efficient at simulating the external world and body, but simulating internal simulations is more complex (although see Riva et al., 2019). When combined, these features may at least partially explain what makes VR suitable for positive emotion induction.

The operating mechanisms behind positive emotions and their influence are better documented, and interestingly, they have complementary benefits to VR. As already discussed, positive emotions present health benefits (Diener and Chan, 2011), can lead to happiness (Diener et al., 1999) and influence cognition and stimuli processing (Phillips et al., 2002; Fredrickson, 2004; Rowe et al., 2007; Holland and Kensinger, 2010). Although there are discrepancies in the literature concerning the physiological markers of positive emotions (Fredrickson, 2003; Kreibig, 2010), they have undoubtedly effects on the cardiac, vascular and electrodermal systems (Shiota et al., 2011). The recent development of a neuroscience of well-being suggests the implication of a broad neural system, involving several neurotransmitters and brain regions traditionally known to be involved in emotion processing (for a review see Alexander et al., 2020).

Beyond complementary added values of VR and emotions for fostering well-being, a user-centered approach is highly needed to elicit optimal user experiences. Fostering positive emotions by means of technology implies taking into account users' age (Liu et al., 2020), gender (Siess and Wölfel, 2019), and physical and cognitive impairments (Roberts et al., 2019; Baker et al., 2020) as all these characteristics may potentially influence users' VR experience (Kenwright, 2018). Personal relevance is another key aspect that may play a major role when opting for preferred VE contents, but has been understudied. Finally, cognitive reappraisal may come into play, as depending on users' goals and regulation strategies employed they will drawn different benefits from emotional experiences (McRae et al., 2012; Brockman et al., 2017). It has also been argued in this overview that VE contents are not intrinsically "positive" or "negative," as their emotional valence depends greatly on the meaning users are willing to give them.

## 4.3 Ethical Considerations and Limitations

Several ethical considerations need to be discussed about positive VR and fostering well-being. Firstly, the devices and material used as VR should be reported clearly, as several devices, with variable levels of immersion, are grouped under the umbrella term of VR. VR material has been reported in the majority of the studies investigated for the present overview (see **Figure 1**). Nevertheless, authors should consistently report the VR material used in their studies.

Although the studies discussed in the present review aimed specifically at inducing positive emotions in users, mixed feelings and negative emotions among elderly users (D'Cunha et al., 2019; Liu et al., 2020; Moyle et al., 2018) and barriers for using HMDs outside lab-settings (Pimentel et al., 2021) have been reported. This raises several concerns, starting with the need to involve elderly users in every feature design, from the early stages of development of a technology to its application (Castilla et al., 2013). Before setting up positive VR experiences for elderly users, some design guidelines that should be considered are simplifying the technology to be accessible to novice users (Kenwright, 2018; Pimentel et al., 2021), limiting the number of choices for a given action in the VE (Castilla et al., 2013), enabling different levels of complexity in order to match users' skills (Castilla et al., 2020), and slow down speech narratives to avoid the double-tasks resulting from such situations (Castilla et al., 2020).

A thorough reflection about which users can benefit from VR interventions, and those for whom it may be detrimental is necessary (Kellmeyer, 2018; Kellmeyer et al., 2019). As literature about VR and emotion induction is nascent, it is normal to start investigating its effects on healthy users before proposing it to more fragile ones. It appears necessary to investigate the benefits, as well as the negative side-effects that may arouse from using VR. For instance, there is to our knowledge no literature about addiction to VR experiences, yet it needs to be investigated, especially when setting positive VR interventions. In line with this observation, it is intriguing that no clear guidelines about the VR exposure duration required and necessary for inducing positive emotions has been reported. For instance, the exposure duration in the cited studies ranges from 90 s (Marín-Morales et al., 2018) to 20 min (Baños et al., 2012; Appel et al., 2020; Miragall et al., 2021) without breaks, and over 45 min with breaks (Anderson et al., 2017). As exposure duration requires to be long enough to elicit positive emotions, but not too lengthy to cause tiredness, confusion or boredom, its thresholds need to be further investigated.

Positive emotions are not valued and expressed in the same way in different cultures (Joshanloo and Weijers, 2014). Research into positive emotions and well-being should take cultural differences into account, which is still rarely the case (Alexander et al., 2020). For instance, the majority of the cited studies has been on conducted on so-called Western, Educated, Industrialized, Rich and Democratic (WEIRD) populations (Henrich et al., 2010a,b). While it does bring some insights on users' opinions and reactions to positive VR interventions, it remains not generalizable to all potential users because of this bias.

Finally, fostering positive emotions should not in any case become an injunction towards constant well-being and the repression of negative emotions. Several limitations have been raised about the broaden-and-build based literature, which supports the idea that positive emotions, cognition and well-being are tightly linked (Fredrickson, 2004; Fredrickson and Branigan, 2005; Fredrickson, 2006). Firstly, the dichotomy between positive and negative emotions have been criticized (Held, 2018). Thus, positive emotions do not always lead to well-being, and can even become detrimental (Gruber et al., 2008; Ford and Mauss, 2014). In addition, negative emotions can also motivate the construction of useful resources (Moss and Wilson, 2015; Pérez- Álvarez, 2016). Methodological weaknesses of the broaden-and-build literature has also been reviewed, pointing mainly at the experimental methodologies employed for supporting the theory (Nickerson, 2007; Pérez- Álvarez, 2016). For instance, the supposed broadening of attention following positive emotions is not consistently found, as the links between emotions and cognition appear to be more flexible than originally conceptualized (e.g., see Huntsinger, 2012; Taylor et al., 2017). Going further, it has been suggested that rather than purchasing constantly positive experiences and happiness, perhaps it is more relevant to pursue a valuable and meaningful life with its ups and downs (Pérez-Álvarez, 2016).

# 5 CONCLUSION

In conclusion, the studies presented in this overview reveal the great potential and future that positive VR has for fostering positive emotions in young and adult users. These positive emotions may in return motivate users towards achieving their goals, or help relaxing and managing negative affects and pain. Key aspects that need to be reflected on before setting up positive VR interventions are users' characteristics and needs, levels of immersion, interactivity, VE contents, sensory modalities involved, and exposure duration required for optimal positive emotion induction. In any cases, fostering well-being through VR should be driven by users' characteristics and needs in the first place rather than by technological progresses, about which there is still a lot of gray area on their long-term benefits and side-effects. Overall, fostering positive emotions through VR should remain a proposition, and should not in any case become an injunction towards constant well-being and happiness.

## AUTHOR CONTRIBUTIONS

KP, DV-P, TG, and LC contributed to the conception and planning of the review. KP identified articles relevant to the topic and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2022.788820/full#supplementary-material

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**Conflict of Interest:** Authors KP and TG were employed at SocialDream

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Socially Supported by an Embodied Agent: The Development of a Virtual-Reality Paradigm to Study Social Emotion Regulation

*Lina Stallmann[1,2†], Daniel Dukes[1,2†], Michel Tran[1,3], Valentin Durand de Gevigney[2,5†], David Rudrauf[2,4†] and Andrea C. Samson[1,2,3*†]*

[1]*Institute of Special Education, University of Fribourg, Fribourg, Switzerland,* [2]*Swiss Center for Affective Sciences, University of Geneva, Geneva, Switzerland,* [3]*Faculty of Psychology, Unidistance Suisse, Brig, Switzerland,* [4]*Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland,* [5]*Institut de Recherche en Informatique et Systèmes Aléatoires, Lannion, France*



**Edited by:**
*Ali Oker,*
*Université de Reims Champagne-Ardenne, France*

**Reviewed by:**
*Thomas Schubert,*
*University of Oslo, Norway*
*Shuo Zhou,*
*University of Colorado Denver, United States*

***Correspondence:**
*Andrea C. Samson*
*andrea.samson@unifr.ch*

**†ORCID:**
*Lina Stallmann*
*orcid.org/0000-0003-1549-9433*
*Daniel Dukes*
*orcid.org/0000-0001-8360-849X*
*Valentin Durand de Gevigney*
*orcid.org/0000-0002-8714-9355*
*David Rudrauf*
*orcid.org/0000-0002-9621-1800*
*Andrea C. Samson*
*orcid.org/0000-0001-6807-3132*

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Social emotion regulation, which can be understood as the intentional efforts by one person to regulate emotions of another person, is something we encounter and benefit from every day, and becomes especially important when a person is unable to handle an emotion or an emotional event by themselves. A paradigm that examines whether someone can perceive and benefit from regulatory efforts by another person, represented here by a virtual agent, would be highly relevant for experimental studies investigating social emotion regulation, as well as for interventions in the clinical and sub-clinical context. Virtual reality (VR) provides perhaps the ideal opportunity to test social interactions and difficulties with them, as it counters typical methodological problems of behavioral experiments, such as the trade-off between ecological validity and experimental control, as well as the difficulty of replicating social situations. The goal of the present methods paper is twofold: to provide a detailed description of the development of a novel paradigm consisting of two scenarios in VR designed to test the efficacy of social emotion regulation, and to present the anticipated results for the target populations of typically developing and autistic youth. Participants are presented with a virtual school environment and take part in two activities with a class of students and a teacher, all of whom are virtual agents. In both scenarios, participants experience a potentially stressful situation and are subsequently offered emotional support by a friendly student. Throughout the experiment, self-reports in the form of virtual smiley scales and psychophysiological measurements are collected as markers of the participants' emotional states. Pilot results will be discussed in line with anticipated outcomes, to indicate that the experiment will be able to show the efficacy of social support by a virtual agent and provide insight into social emotion regulation for different populations. The school environment and the character of the friendly student also have the potential to be adapted for follow-up experiments on additional aspects of social emotion regulation for a variety of contexts.

**Keywords: virtual reality, cyberball, virtual agent, social support, social exclusion, social emotion regulation**

## INTRODUCTION

Emotion regulation, the process of modifying how one experiences and expresses one's emotions, is an integral part of a person's life and highly relevant for their wellbeing (Gross 1998; Gross 2015). Social, or interpersonal, emotion regulation can be understood as the intentional efforts by one person, the regulator, to regulate the emotions of another person, the regulatee (or target) (Reeck et al., 2016; Nozaki and Mikolajczak 2020). It can also be one person's efforts to regulate their own emotions by receiving and implementing input from another person - this in turn is called *intrinsic*, as opposed to the *extrinsic* part played by the regulator (Zaki and Williams 2013). This paper presents a method to study social emotion regulation, from the perspective of the regulatee, by simulating situations of social support in virtual reality, and explores why and how this method could inform research on populations who experience difficulties regulating their emotions in general, and youth with and without autism in particular.

Social emotion regulation is an important aspect in the field of emotion regulation that has grown increasingly in the last decade, with over 350 results on Google Scholar including 'social emotion regulation' since 2011, compared to 34 from the decade before. Similarly, for 'interpersonal emotion regulation' results grew from 134 to over 2′800 between the same time periods. Social emotion regulation is essential in a variety of contexts, particularly when someone is not able to appropriately deal with their emotions by themselves. Such inability may be caused by age, when a child is still developing their emotional competences (Martin and Ochsner 2016), context, when one's abilities are temporally impaired (Marroquín 2011), or the magnitude of the precipitating event, when a person is overwhelmed, but it appears to be particularly prevalent for individuals with neurodevelopmental disorders, since they consistently report emotion regulation difficulties (Cai et al., 2018).

People with neurodevelopmental disorders, specifically those on the autism spectrum, typically present with a variety of difficulties in emotion regulation at all stages of the regulatory process. They tend to have trouble with recognizing and understanding emotions and might thus not be able to set appropriate or relevant regulation goals (Mazefsky and White 2014). They are also often less flexible in their choice of regulatory strategy due to a reduced variety of options and the preference for a few, familiar ones, and also tend to have more difficulty implementing them (Samson et al., 2012; Samson et al., 2015a; Samson et al., 2015b; Cai et al., 2018). Difficulties in satisfactorily regulating one's own emotions can affect one's social life, but there are additional challenges when it comes to the regulation of another person's emotions: Failure to correctly identify another person's emotional state and their need or wish for regulation, the choice of a regulatory strategy not suitable for the other person's disposition, and the inappropriate implementation of an otherwise sensible strategy, can all be detrimental to the interaction with said person. At the same time, the probability of such failure is highly dependent on one's social understanding and skills (Nozaki and Mikolajczak 2020) - skills that individuals on the autism spectrum often struggle with (Williams White et al., 2007).

From the perspective of the regulatee, potential difficulties also concern one's self-regulation abilities. As formulated by (Zaki and Williams 2013), the intrinsic part of the interpersonal regulation process, i.e., the perception and reception of the process by the regulatee, is dependent on one's ability to *label appropriately* how one is feeling and to recognize intended *safety signaling* by others. But whether one can benefit from another person's attempt is also dependent on one's social motivation, i.e., the preference of the individual to orient to the social world, seek social interactions and work to maintain social bonds (Chevallier et al., 2013). It is not only: Do I understand regulation attempts by others? But also: Do I seek them out and/or appreciate them? This is particularly important, since research suggests reduced social motivation as a main characteristic in autism (Chevallier et al., 2013; Treichel et al., 2021). When taken into consideration with the many significant points raised above, the study of social emotion regulation becomes particularly important for people with emotion regulation difficulties and/or social interaction in general and for individuals on the autism spectrum in particular, in order to gain a more profound understanding of the processes involved in order to provide targeted support and interventions in the clinical and non-clinical context.

The study of social situations and interactions faces the perennial methodological problems of getting the balance right between ecological validity and experimental control, and the difficulty of replicating situations including the verbal and nonverbal behavior of a person (Blascovich et al., 2002; Meuleman and Rudrauf 2018). These problems can undoubtably help explain why the experimental research on social emotion regulation is relatively restricted, in spite of its importance. Many papers deal with its theoretical implications and connections with other constructs, be it a collection of regulation strategies (Niven et al., 2009), an integration with the concept of empathy (Zaki, 2020), or the role of maternal co-regulation for the development of socio-emotional competences (Silkenbeumer et al., 2016). Others with a more empirical approach rely on recall and self-assessment about social emotion regulation skills, strategies and goals (Williams White et al., 2007; Coats et al., 2008; Hofmann et al., 2016; Liddell and Williams 2019; Chan and Rawana 2021). There are notable experimental paradigms used in related fields, such as the manipulation of physical closeness by having mother-daughter dyads either hold hands or not, and examining its impact on so-called 'load sharing', the distribution of the load of emotional distress among relationship partners (Lougheed et al., 2016), and also non-experimental studies like the exploratory observation of co-regulation tactics employed by mothers and their children with autism (Gulsrud et al., 2010). Still, re-enactment or simulation of the actual, relevant situation for the experimental assessment of social emotion regulation is as rare as it is difficult. One way to bypass these problems was chosen by Hallam and colleagues in an fMRI study, who showed participants pre-recorded videos of other people supposedly watching the same emotional video clip as they were at the same time and asked them to help the others regulate their reactions (Hallam et al., 2014).

Virtual Reality thus enriches this area of research by allowing us to take a look at social interaction in a maximally controlled environment, using virtual agents as either the intended regulator or regulatee for the participant. By developing relevant environments and scenarios, we now have the ability to untangle social interaction in concrete situations which a person can experience more acutely, even possibly enhancing relevant stimuli, while at the same time benefiting from a unique level of standardization and control. This is done with the expectation that virtual social cues can elicit affective experiences and reactions equivalent to, or at least very similar to, those of the real world (for a review of relevant studies, see Bombari et al., 2015).

The two virtual scenarios created in this current project focus on social emotional support. Social support can be defined as an individual's or a social network's "provision of psychological and material resources intended to benefit an individual's ability to cope with stress" (Cohen, 2004, 676; Nozaki and Mikolajczak, 2020). It can thus only be considered a strategy of social emotion regulation, when defined as intentional, not contextual, and specifically focused on emotion. We operationalize the term here as an offer of a supportive regulatory attempt towards a person experiencing emotional distress and focus on the receiving end, the regulatee.

The backdrop is a novel school environment with the participant being introduced as a new student and experiencing their first day at school. By making the participant the regulatee and a virtual agent the regulator, we aim to assess the impact of emotional support by another, rather unfamiliar person on one's emotion regulation. This will be assessed in the two different situations and with two different populations here, namely school-aged children and adolescents who are either typically developing or who are on the autism spectrum and who have no intellectual disability. Each scenario provides a situation to which people respond negatively: the first concerns an ambiguous or confusing situation of being scolded by a classroom teacher. An agent, a fellow student, who has previously been established as friendly towards the participant, then gives a positive appraisal of the situation. The idea is that the participant can adopt this for their own cognitive reappraisal, the reinterpretation of emotional events, which has been shown to be a potentially highly apt self-regulation strategy (Gross, 2002). The second scenario concerns being excluded from a group in the context of a ball game, an adaptation of the Cyberball paradigm (Williams and Jarvis, 2006). After experiencing exclusion, once again the fellow student offers support in the form of a positive appraisal of the situation, but this time it is juxtaposed with two other forms of social support a person could benefit from: distraction by the virtual agent away from the exclusion situation, a strategy aimed at emotional disengagement (Sheppes et al., 2011), and social buffering, an effect capable of ameliorating stress responses through the sheer presence of another person. Social buffering occurs in many situations although not always necessarily intentionally (Zaki and Williams, 2013; Bratec et al., 2020), and can be seen as a baseline to every condition including the agent.

These regulatory strategies and/or processes are situated at different stages of the social emotion regulation process, are employed to differentiate potential layers of a discovered effect, and provide evidence of the strategies to be focused upon in the future, since they might differ in efficacy. This is addressed in the Cyberball conditions and not in the randomized Classroom conditions, due to practical assessment restrictions concerning the large number of subgroups (particularly when recruiting clinical populations) that would be necessary to vary three forms of support over three conditions. In terms of autistic individuals, there is reason to believe that distraction as an attentional deployment strategy might be an effective strategy, while cognitive reappraisal might not be (Samson et al., 2012). Social buffering is believed to be reliant on at least a normatively well-established relationship with a person (Bratec et al., 2020) that this experiment might not be able to create.

The goal of these scenarios is thus to present the participant with relatable virtual situations that trigger negative emotional responses and subsequently offer emotional support through an agent. To achieve this, a number of areas have to be covered: First, the main target groups are school-aged children and adolescents with and without developmental disorders, with these being at critical stages in their life concerning their emotional and social development (Samson et al., 2015a; Volkaert et al., 2020). The scenarios therefore need to be developed with this age group in mind. Second, the context and environment should be engaging and interesting to the participants, while still being standardized enough for experimental conditions. Thirdly, the relevant virtual characters need to be able to form a relationship with them, since social support is partly dependent on the relationship between the regulator and the regulatee (Reeck et al., 2016; Lindsey, 2020). And lastly, the emotional reactions need to be measured reliably in a way that is accessible to children. The explanations of how we worked towards this goal will be supported by results of a pilot study on a typically developing adult population and by feedback from youth with and without developmental disorders.

This article presents a method suitable to study social emotion regulation in virtual reality. Using said method, our ongoing study of our target group of children and adolescents serves as an evaluation of the virtual environment for the purpose of assessing the efficacy of virtual social support, and as a step towards a wider approach of studying social emotion regulation in VR.

Gaining insight into this part of the process of social emotion regulation will ultimately help uncover the kind of support that can and should be provided to young individuals struggling with emotion regulation. This includes finding out the type of regulatory strategy to focus on and the direction of a training, either towards understanding the intent and content of the regulatory attempt, or towards a more habitual call for support from others.

## MATERIALS AND EQUIPMENT

### Hardware and Software Needed for the Experiment

The virtual world was designed and programmed in Unity3D 2018.2.21f1 and C#, with the visual editing, modeling, animation,

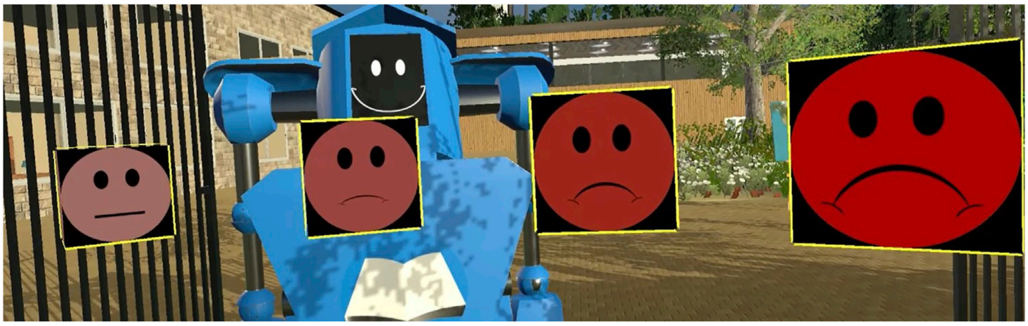

**FIGURE 1 |** The negative 4-point smiley scale in front of robot Marvin during the tutorial.

sound production and other aspects developed using a list of other software (see **Supplementary Material**). The Unity Asset Store provided two sets of VR avatars that were purchased to create the virtual human characters populating the school grounds, *Toon people* for the teacher (JBGarraza, 2021b) and *Toon kids* (JBGarraza, 2021a) for the students. Other Unity assets were obtained for free (see **Supplementary Material**) or developed in-house. Character voices were recorded on a Zoom H5 portable recorder for both a German and a French version.

The experiment is run on Microsoft® Windows 10 in Steam® VR 1.13.10 using the Unity3D game engine and hardware of the HTC VIVE© line, consisting of a head-mounted display with built-in microphone, one wireless hand-held controller and two base stations. Depending on the location of the session, in lab or off-site, the set is either from the VIVE© Pro series with built-in audio straps and base stations and controllers 2.0, or from the VIVE© series with additional headphones (Beyerdynamic Custom Street) and base stations and controllers 1.0. The sessions are recorded as in-game screen capture and externally as camcorder footage from a corner of the room, using a Canon Legria HF R806. The participant spends the experiment sitting in a revolving chair with the possibilities to turn around in it freely and use the controller for any other movement and interaction.

## Emotion Self-Reports

As the main measure of emotional experience, two 4-point smiley scales were created to pop up one after the other as rows of floating boxes in the virtual environment and to be grabbed by the VR controller whenever a self-report reply is required (see **Figure 1** for a picture of the negative scale). The scale always appears in front of the participant. One scale is of negative valence, one of positive, with accompanying voice messages by a robot named Marvin (see **Figure 1**), stating respectively "please state how negatively you are feeling right now" and "please state how positively you are feeling right now". The scales consist of the categories "Not at all", "A little", "Medium" and "Very" and are read aloud by Marvin each time the controller touches the respective smiley. For the benefit of the reader, the English translation of the original language versions is used here (see **Supplementary Material**, **Section 2**, for the other languages). The respective smiley is chosen after being grabbed by the participant for 3 s and there is no time limit for the response.

## Psychophysiological Measurement

For the relevant physiological signals, Biopac® Bionomadix 2-CH Wireless hardware is used, with the recording software Acqknowledge 5.0.2. The four domains collected are pulse (PPG), skin conductance (EDA, exosomatic with direct current), respiration (RSP) and heart rate (three-lead ECG), thus requiring the two joint transmitters for PPG-EDA and RSP-ECG (BN-PPGED-T and BN-ECG2-T respectively). For EDA, one-way adhesive gel electrodes (EL507) are attached to the middle and fourth finger of the non-dominant hand, while one-way adhesive cloth snap electrodes (EL513) are also used for the ECG. Said hand is then rested on the armrest of a revolving chair the participant is asked to sit in, to reduce artifacts in the recording. The recording includes trigger points at important events throughout the experiment that are being fed into the recording from the SteamVR log through a Neurospec trigger box converting from a USB serial device to a parallel port. To ensure an accurate interpretation of the collected data, a baseline period of 3 min is collected early in the experiment. Post-processing scripts were written using Python 3.0 and the integrated development environment Spyder. Kubios HRV 2.2 is used for manual artifact correction and calculation of heart-rate values.

## Post-Experiment Questionnaires

A VR questionnaire (VRQ) administered post-experiment consists of demographic information, an item on whether the participant has already experienced immersive VR to check for potential effects of experience, and several open or mixed questions concerning their experience of the VR experiment, designed to help improve the environment in the future: They are asked how they found the VR experience in general, whether they noticed anything about the experiment, how they experienced the steering/control inside the environment (with a 5-point difficulty scale and free lines to comment), whether they would change anything about the experiment, and whether they found the virtual characters likeable. In addition, as a manipulation check for the social relevance of the presented virtual agents, participants are questioned about the two most notable students of the school environment, specifically, the friendly student offering social support in both scenarios, and the "troublemaker", the student disrupting the class in the Classroom scenario. Their perceived relationship with the two characters is evaluated with two 5-point scales on valence and closeness of the relationship each, and participants are given the opportunity to comment verbally to add to their responses on the scales, and about whether they felt that the two virtual agents had any impact on their own behavior, again with two 5-point scales to measure the extent and valence of that impact plus a further opportunity to comment verbally. The questionnaire ends with a manipulation check on the exclusion and social support of the Cyberball scenario: participants can check the respective boxes whether and in which games they felt included or excluded, and are asked what they think about the friendly student's arrival after the third ballgame, and whether they felt comforted by him (see procedure in 3.1.3 below). In case the participant has trouble understanding the scales and questions, the questionnaire is completed with the help of the experimenter.

# METHODS

## Overview of the Experimental Procedure

The experiment was performed in accordance with the Declaration of Helsinki and approved by the local ethics committee. When participants arrive and have given their informed consent, or if their parents have given theirs when the potential participant is under 18 years old, the participants are instructed to sit on a revolving chair in the center of the experiment room, calibrated as the starting position for the VR equipment. They are free to turn and move their arms in every direction to orientate themselves and take in the visual experience of the virtual world.

All four points of psychophysiological measurements (PPG, EDA, RSP, ECG) are attached on the body and the non-dominant hand, with the experimenter showing the resulting signals on screen and describing their general function. Then the HMD and handheld controller are explained and the experimenter outlines the order of events that is to come: First a tutorial is given of how to use the controller and interact with the environment, secondly there is a break of 3 minutes to create a baseline for the physiological measurements, thirdly there is a situation in the classroom with the new class, and lastly, there are ball games in the school's gymnasium. The participants are instructed that they can stop the experiment at any point if they feel dizzy or have other problems and that the experimenter will always be near to help. After this explanation and when they have no more questions, the participant puts on the HMD, receives the controller for their dominant hand, and is ready to start the experiment. The camcorder recording the session is started.

The VR experiment itself consists of the forementioned introduction to the novel virtual environment, including the tutorial of about 2.5–4 min, and a 3-min baseline period for the psychophysiological measurements, a first "Classroom" scenario of about 8.5–10 min, then a "Cyberball" scenario of about 7.5–8.5 min, followed by a reward sequence at the end. In total, completion of the VR experience should take 25–30 min—depending on the participant's reaction times and how much they choose to explore the environment. When it is finished, the experimenter helps the participant remove the HMD and the different points of physiological measurement. Once the participant has completed the post-VR questionnaire, and when they have no further questions or comments, they are remunerated for their time, thanked, and free to leave.

### General Aspects of the Environment

The developed virtual environment consists of the school grounds which are accessible from a front gate on a suburban looking street. The front gate functions as the starting point of the participant's experience. Implementations in the virtual world to make it more immersive include explorable features of the grounds like green and planted areas with grass and leaves moving in the wind, picnic and play areas on the playground, additional classrooms (empty of people), a hot-air balloon (relevant for the ending of the experiment), a pond, a fenced-off forest at the back, and a rotating windmill and mountain scenery visible in the distance. In addition, sound is spatialized, characters move their lips in synchrony with voice recordings, and there are environmental sounds like birds chirping noisily outside (and quieter inside) and the students' excited cries while playing ball in the gymnasium. To add to the playing experience during the Cyberball games, every throw from the participant results in a celebratory sound, while there is no score being kept to avoid inducing competitiveness.

Several times throughout the experiment, after a virtual character has announced a next step or task, glowing circles and lines on the ground are incorporated as a visual guide to where or in which direction to teleport. Following the instructions and teleporting to the appropriate place acts as a trigger for the next step of the experiment to begin. This means, while participants can often teleport around freely and discover the whole map, the experimental paradigm does not continue unless they follow the lines or enter the circles. Indeed, participants are eventually encouraged by the experimenter to resume their places and tasks when they have decided to roam the school grounds instead. Other characters of the virtual world only interact with the participants when the latter are following the instructions and partaking in the scenarios, keeping the experience as standardized as possible without constricting wishes to explore.

### The Introduction in Virtual Reality

The participant starts off at the front entrance of the school grounds and is greeted by Marvin, the school's janitor robot. Marvin welcomes the participant at their new school and demonstrates how the controller can be used to grab virtual objects with a button activated by the index finger (holding the object until the button is released) and teleport to a spot of one's choice within a certain distance using the directional pad activated by the thumb (**Figure 2**). The emotion smiley scales are explained and presented in-game for the first time and, after a successful response on both, a star appears that can be collected (**Figure 3**). Marvin states that he would be delighted if the participant could collect stars that they might encounter during their day, since he has lost his and is looking for them.

**FIGURE 2 |** Usage of the hand-held controller to teleport.

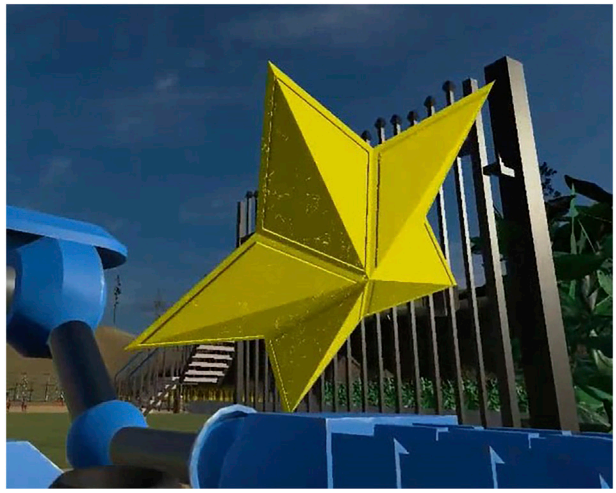

**FIGURE 3 |** Example of the stars collectable as rewards during the experiment.

In fact, a star appears each time the participant has completed an important step in the two scenarios. When practicing the teleportation method, the participant is asked to teleport into a white circle marked on the ground in front of an easel carrying a map of the world (visible in **Figure 2**). The participant then has to wait for 3 minutes looking at the world map, before Marvin continues the experiment by inviting the participant to go to their class. A blue line on the ground shows them where to teleport, step by step, but they are also free to explore the school grounds before finally arriving in front of their class for the experiment to continue.

## The Classroom Scenario

Once the participant arrives in front of the classroom in a marked blue square, they are invited in by the female teacher. When inside, the participant is asked to introduce themselves to the other students. The introduction task ends either when the experimenter presses a button, or automatically after 10 s. After introducing themselves to the class, participants can collect a star appearing on top of the teacher's desk as a reward. The teacher then asks the participant to sit down next to student Pete, a place marked by a white circle, and Pete introduces himself and also asks the participant to sit down next to him. Pete is the friendly student who will provide support throughout the paradigm (see **Figure 4**). He is, like the other students, a more cartoon-like than real-looking human character, since this has not only been shown to be more readily accepted by people, but also to be perceived as more friendly (McDonnell et al., 2012; Ring et al., 2014). Since studies evaluating the difference a virtual agent's gender may make on their effect on participants have as yet not been conclusive (Krämer et al., 2016; Shang et a., 2019), and to keep the design simple, it was decided on the toss of a coin that the virtual agent would be designed as a boy (see **Section 4.1** for a discussion of this point). He is the first and only student of the class who directly talks directly to the new arrival, is seated closer to him than anyone else, and is the only one who introduces himself, thus establishing an at least normatively special and positive (or at the very least, neutral) connection to the participant. The teacher then explains they will be watching a movie (A short introduction of the Hubble Telescope in the respective language). The participant is asked how they feel at this stage and the smiley scales are presented. When successfully answered, the scales disappear and the movie starts. During the playing of the movie, the participant cannot teleport away from the seat they are in (setup seen in **Figure 5**).

The teacher interrupts the movie three times, forming three different conditions of different intensity of stress induction presented in a randomized order across participants. Each time, the participant is asked twice how they feel and the negative and positive smiley scales appear: First, the teacher scolds a student, then Pete says he is not sure about the cause of this and the participant is prompted with the scales for the first time. For the second time, the teacher resumes the scolding, next Pete offers emotional support and the participant is prompted with the scales once more. This effectively splits the situation into two halves that can be compared later in their effect on the participant, one without support and one with social support (see **Figure 6**, $t_{CR1}$ and $t_{CR2}$).

In the "Ambiguous" condition, the teacher scolds someone who apparently has made noises, while looking directly at the participant. Pete explains he is not sure whether the participant is addressed. The other students are either looking at the participant (half of the class) or the student behind them, the "troublemaker" (other half of the class, see schematic depiction of the three conditions with lines of sight displayed in **Figure 6**). Pete proceeds to comfort the participant by saying that it was probably not them who was the target of the scolding.

In the "Participant" condition, the teacher also scolds the person who has made noises, while looking directly at the participant. Pete again says he is not sure whether the participant or the troublemaker behind them is the target. This time, the other students are all looking at the participant.

**FIGURE 4 |** Pete, virtual agent and supportive fellow student: face and body (assets by JBGarraza, 2021a).

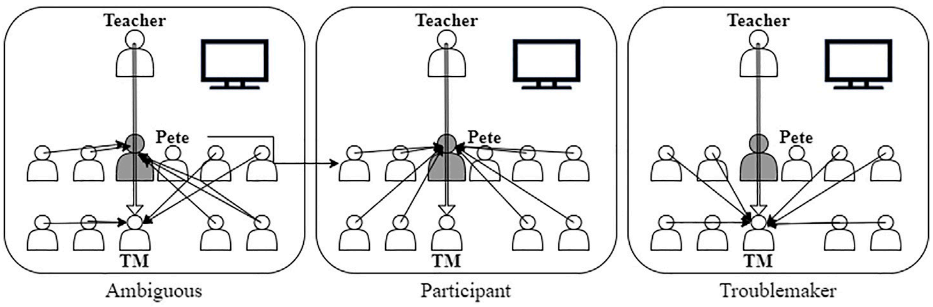


**FIGURE 5 |** Classroom setup in the Classroom scenario, going through three possible intensity conditions of stress induction concerning the direction of the student's gazes towards the (dark grey) participant in the center: Ambiguous, Participant, Troublemaker (TM).

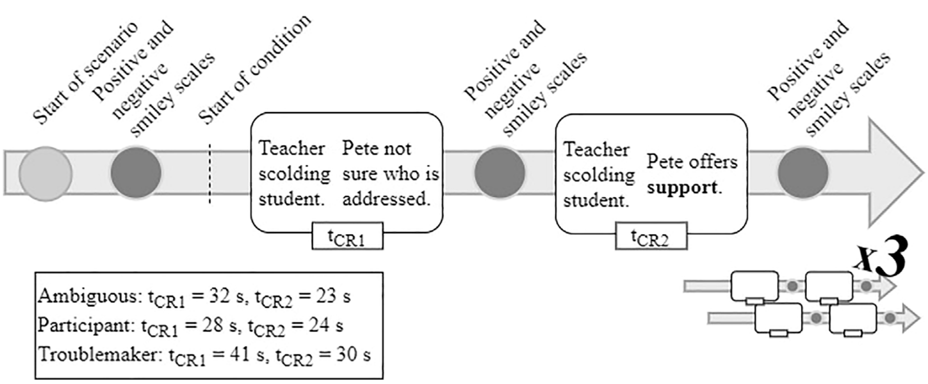


**FIGURE 6 |** Sequence of each condition of the Classroom scenario with the three conditions in a randomized order.

Pete again comforts the participant and explains that they were probably not the actual target.

In the "Troublemaker" condition, the teacher again scolds the person who has made noises, while looking directly at the participant. Again, Pete expresses uncertainty about whether the participant is the target. This time, the other students are all looking at the troublemaker, the student behind the participant. Pete comforts the participant again, saying that they were probably not the target.

After all three conditions have appeared, the movie ends and the participant can collect a star as a reward, after which

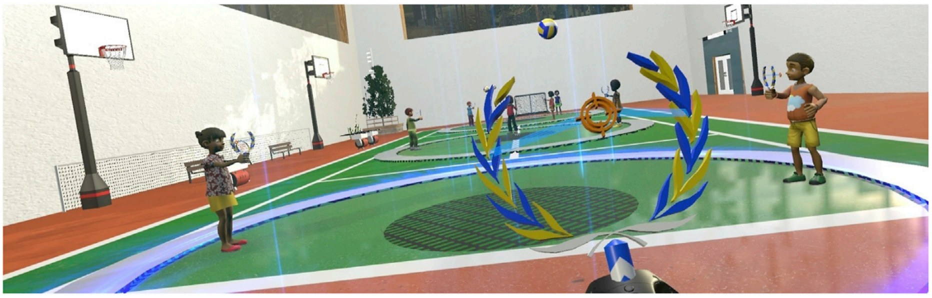

**FIGURE 7 |** Slingshot, ball and play areas of the gymnasium during the Cyberball scenario.

the teacher dismisses the class and the students leave the building.

### The Cyberball Scenario

The participant is told by the voice of Marvin that Pete is waiting for them in the hallway. After they have joined Pete in the hallway, Pete tells them that the students are playing ball games in the gymnasium and that the participant can join each game once one of the three students playing each game leaves. The play area is indicated by a blue circle. The participant is asked to follow Pete towards the gymnasium as he continues to walk along a blue line on the ground. Once they arrive, a slingshot-like throwing device or bat appears on top of the participant's controller (see **Figure 7**).

Pete explains that they can use the button activated by the index finger on their controller to throw the ball when it has been thrown at them, and leaves again. The participant then goes through three consecutive games of 60 s each, with play areas spread inside the building (also seen in **Figure 7**), constituting three conditions in a fixed order. The different conditions, inclusion in the game to exclusion from the game to then exclusion with the offer of emotional support, can then be compared in terms of their effect on the participant.

Each play area can house three players for a ball game, although the first one only has two players as the participant enters the room, allowing the participant to begin immediately. The second and third game can only be joined once one of the playing agents has left the relevant play area. After 50 s of each game, the participant is asked how they feel with the smiley scales. Then, 15 s after each game has finished, they are asked again. During each game and the 15 s afterwards, the participants are not allowed to leave the play area and can only teleport around inside of it. After they have picked their answer on the second smiley scale, they are free to leave the area and can join the next one once one of the other players has left. The three conditions are shown in **Figure 8**.

In the first (Inclusion) condition, two students play with the participant, with the participant generally receiving the ball a third of the time, i.e. at the same frequency as the other two players.

In the second (first Exclusion) condition (without social support), two students throw the ball to the participant for the first two times. After that, they exclude the participant completely for the rest of the game.

In the third (second Exclusion) condition (with social support), two students throw the ball to the participant for the first two times and afterwards exclude the participant completely for the rest of the game. After the game, Pete joins the participant standing in the gym and there are three options for the intended social support, varying randomly between participants: either Pete is only present and keeps quiet for 15 s (s), or he talks to the participant about information related to ball playing for 15 s and thus offers distraction, or he talks to the participant, offering a positive appraisal of the situation for 15 s. As a final reward, a star appears and can be collected.

### The Reward Sequence

After the last star has been collected, robot Marvin's voice invites the participant to take a hot-air balloon ride over the school grounds. Marvin, the teacher and all the students are already waiting next to the balloon. Marvin explains that he would like to reward the participant's successful star collecting with a balloon ride together with Pete. This also serves as a positive final experience to leave participants with the best possible emotional state after having gone through the two scenarios created to induce a negative emotional reaction. After everyone has started clapping and the participant has teleported into a white circle where Pete is already standing, they are automatically transported into the balloon that begins to take off. A tune is played and a few stars dance around the basket of the hot-air balloon while it is slowly rising up. The surrounding neighborhood and landscape come into view. At this point, the experimenter helps the participant remove the HMD.

## Pre-Processing

The two data sources for pre-processing and analysis are the SteamVR data and the Acqknowledge recording of psychophysiological data in reference to the relevant time markers transferred from the VR experiment. The smiley self-reports, coded as values from 0 to three for each scale, are exported from the SteamVR log in long-format single file and ready to be analyzed. The Acqknowledge recording is converted to a Matlab file and slices for the relevant time frames, or epochs, are extracted for the two domains that are in focus here: skin conductance and heart rate. For both domains, the epochs are

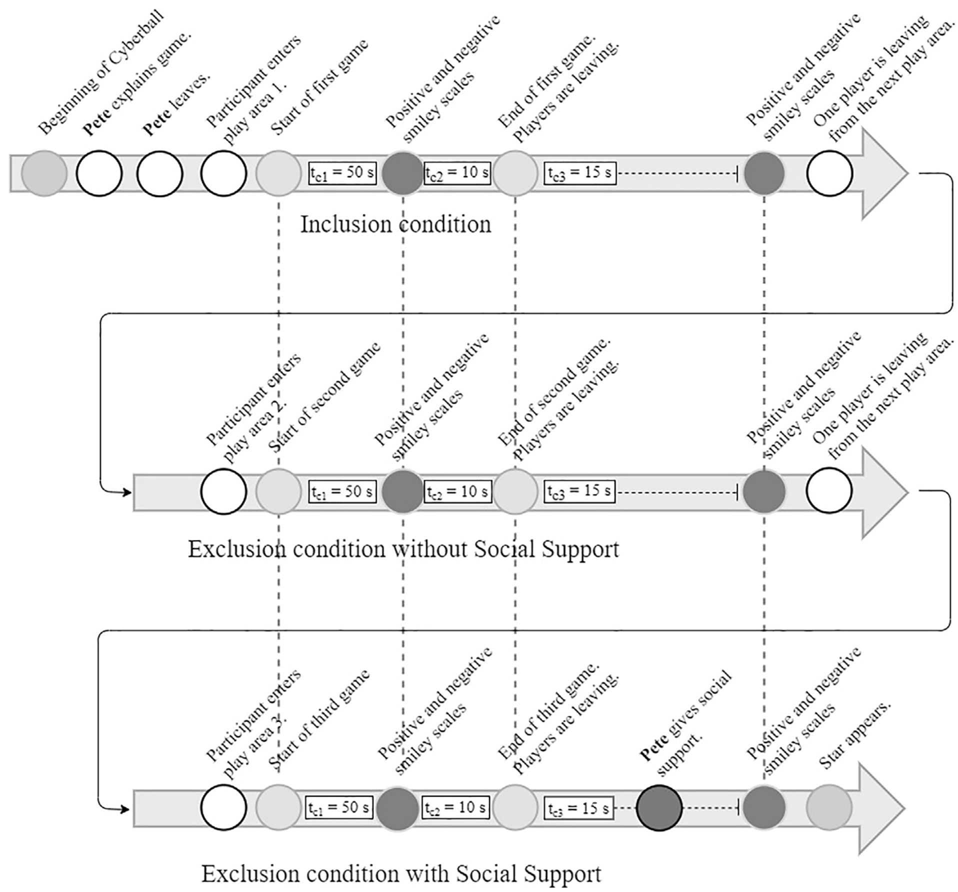


**FIGURE 8 |** Sequence of the Cyberball scenario with the three conditions in a set order.

each half of each condition in the Classroom scenario (**Figure 7**, $t_{a1}$ and $_{a2}$, $t_{p1}$ and $_{p2}$, $t_{t1}$ and $_{t2}$), each condition in-game and during recovery period respectively in the Cyberball scenario (**Figure 8**, $t_{c1}$ and $t_{c3}$) and the last minute of the baseline period at the beginning.

Individual skin conductance level (SCL, tonic EDA) minimum and mean values for these slices are exported and range-corrected using the minimum of the baseline and the formula suggested by Lykken et al. (1966): $\varphi_{\rho} = (\rho_{ix} - \rho_{i(min)})/(\rho_{i(max)} - \rho_{i(min)})$, with $\rho_{ix}$ as the raw value and $\rho_{i(max)}$ and $\rho_{i(min)}$ as the maximum and minimum overall value of the respective participant. Skin conductance response (SCR, phasic EDA) is derived from the EDA signal by high-pass filtering with a frequency cutoff of 0.05 Hz in accordance with the Acqknowledge five Software Guide (Braithwaite et al., 2013). It is exported as mean and maximum values and as the peak count (non-specific SCR), the latter being computed using the SciPy function *arglextrema* from the scipy. signal package (Virtanen et al., 2020), and their cumulative amplitudes.

The heart rate signal slices are loaded into Kubios and artifacts are corrected manually, before the two variables, mean heart rate (or beats per minute) and root mean square of differences (RMSSD) between interbeat intervals, are computed. The latter being a measure of heart rate variability that can be used with ultra-short time spans of 1 minute and lower (Nussinovitch et al., 2011).

Having prepared the data in this way, it is possible to analyze the different variables using repeated-measure ANOVAs and paired-sample T-tests over the different conditions.

# RESULTS

## Pilot Results: Implementations and Adjustments

The presented paradigm includes two scenarios: Classroom and Cyberball. A pilot study using an earlier version of the paradigm (article submitted, Stallmann et al., 2021) with a sample of 29 typically developed adults recruited through online study advertising and university bulletin boards, showed that the experimental design (here with a focus on the Cyberball scenario) was able to elicit the desired emotional responses: participants reported more negative and less positive emotions in the exclusion conditions than in the inclusion condition, and less negative and more positive emotions after having received social support. However, the psychophysiological measures, specifically electrodermal activity and heart rate variability, while suggesting differences between conditions, were inconclusive. When asked an open question on how they liked the experiment in the earlier, less detailed version of the post-experiment questionnaire, participants reported that they experienced it as positive and interesting or exciting. The tutorial at the beginning was accepted well by the participants, there were no dropouts, and everyone managed to get through the experiment using the controller. Still, due to a few observations during this earlier pilot and other concerns regarding our intended target populations, certain aspects and details in the design have been modified and are presented below.

After taking into account the intended target population of people with developmental disorders and pre-testing of the scale with children, the positive and negative smiley scales were reduced from a 5-point to a 4-point scale, since 5-point scales seemed to overwhelm the children in the pre-test. As this scale is also part of other connected studies and integral to our emotion report, young participants are presented with the scale beforehand, either on a touch screen or with the help of cardboard boxes, in a short training session in which its logic is applied to real-life situations familiar to the participants. Another adjustment for a younger and potentially less physically mobile or cognitively impaired population was the implementation of a non-self-steering mode: if the experimenter sees the participant having acute trouble with teleportation during the tutorial, the self-steering can be modified so that the participant can confirm whether they would like to be teleported to a predetermined spot in their visual field via the grabbing button at their index finger. This continues throughout the experiment and enables the experience to be as close to the self-steering one as possible.

Other adjustments making the relevant points of comparison as standardized as possible affected the Cyberball scenario: Having the three play areas spread across the playground, as it was in the previous version, prompted some participants to leave the ongoing games when they were getting bored (for example, when they were excluded) to explore the rest of the school grounds. To possibly instill a stronger feeling of commitment and make the self-report and psychophysiological data more comparable, the setting was changed to that of a gymnasium, making it less of a free-time activity and more of the continuation of school hours. Importantly, the play areas are also enclosed by an invisible wall from the point the participant enters them to play until they have responded to the second smiley scales 15 s after the ball game has finished. This restricts movement, distraction and other confounding influences on the comparison of the conditions.

Further testing is being carried out with the current version of the presented paradigm and using the current post-experiment questionnaire. This time, 30 typically-developing youth and 30 autistic youth without intellectual disability will take part for statistical analysis of the self-report and psychophysiological data (see **Section 4.2** for sample size calculation). Taking a first, descriptive look at the questionnaire data, 20 of the 23 participants tested so far (age range: 9–17 years, four of 23 on the autism spectrum), recruited through sports clubs and through associations, gave positive feedback when asked about their general experience, and there were no dropouts. When focusing specifically on the four participants on the autism spectrum, two reported finding the experiment interesting and fun, while the other two found the experiment to be made for children younger than them. Steering through the environment was found to be easy, scoring a general average of 1.4 on a difficulty scale from 1 to 5, with three of the 23 participants marking a three and everyone else answering lower. This experiment thus promises to be indeed quite accessible to a younger target group.

The participants rated their relationship to Pete, the supportive student, on average as rather close (3.9 on a scale from 1 [very distant] to 5 [very close]; $SD = 1.0$) and rather positive (4.3 on a scale from 1 [very negative] to 5 [very positive]; $SD = 0.9$), while that to the "troublemaker", the disruptive student, was judged as rather distant ($M = 2.0$; $SD = 1.0$) and rather negative ($M = 2.2$; $SD = 0.9$). Concerning the Cyberball scenario, the majority of the participants (13 of 17 filling in the respective items of the questionnaire) felt included only in the first ball game. 11 of 17 felt excluded in both the second and third ball game, while four people only felt excluded in either the second or third. When being asked what they thought of Pete's appearance after the game, 12 of 17 participants responded positively about it, and when specifically asked whether he had been a comfort to them, 9 of 17 agreed that indeed he had. When focusing only on the participants grouped into the two support conditions in which Pete is talking to the participant (appraisal and distraction), 8 out of 11 agreed.

While the manipulation seems to be adapted to this young population, this also shows the limits of the experimental situation created. Clearly, not everyone will react in the same manner in a social situation: four participants reported that they did not feel supported since Pete had not stayed with them during the games, but only reappeared afterwards. Furthermore, the aspect of it being virtual adds another possible filter: Two participants expected Pete to present them with the next task of the experiment instead of coming to support them, as he had already played a big part in structuring the other two scenarios, representing a potential bias because of one's expectations about the structure of computer games. One participant stated that they did not care about Pete being there at all, since everyone was computer-generated anyway.

One open question concerns the importance of the supportive agent's gender, as current research has not yet established the specific contexts in which either same-gender or cross-gender interactions might be more beneficial (Krämer et al., 2016). While the questionnaire data indicates that both male and female participants accepted Pete (a boy) equally, as intended, future research could include a design to evaluate the role the regulator's gender might play in social emotion regulation, and adaptations of the paradigm for more individual and targeted intervention approaches could consider more variability in the regulator's appearance.

## Anticipated Results

When conducting future studies on the two targeted populations of typically-developing and autistic children and adolescents, we

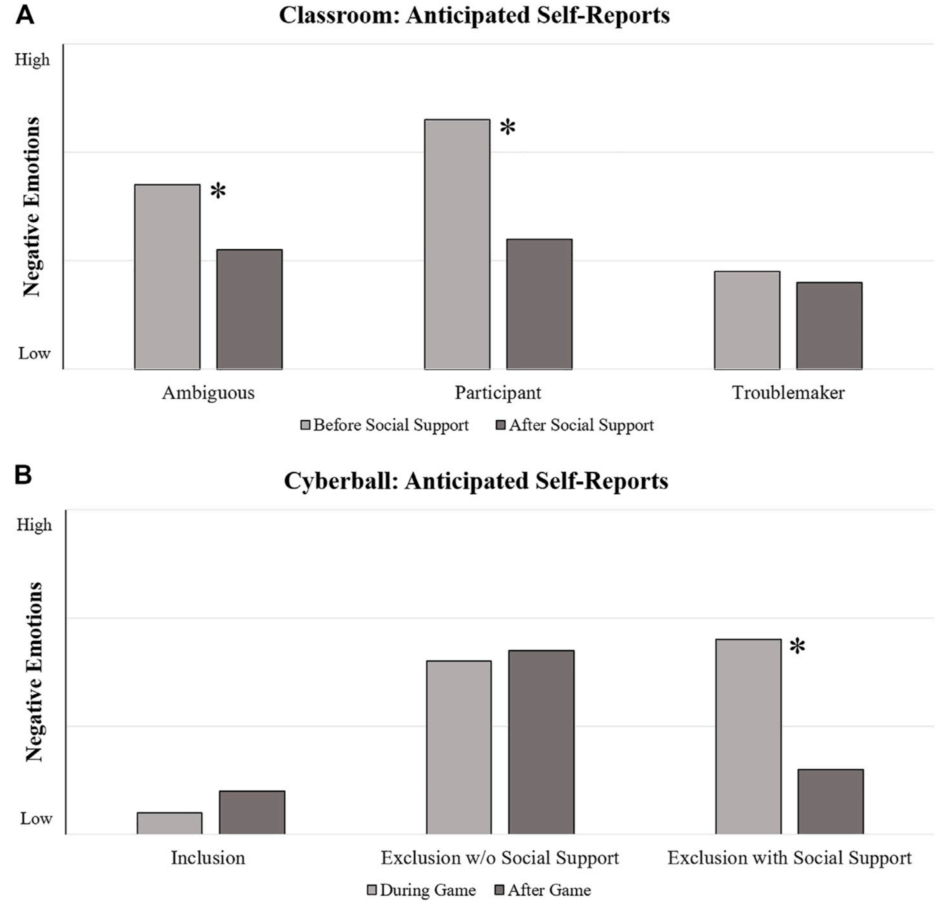


**FIGURE 9 |** Anticipated negative self-report results for both scenarios, Classroom **(A)** and Cyberball **(B)**, in the typically developing sample. Significant effects are marked with an asterisk.

expect a pattern similar to that of a previous version with adults to emerge. Considerations of feasibility, distributional convergence of the data and of a-priori power analyses using G*Power 3.1.9.7 (Faul et al., 2007) resulted in a goal of 30 participants per group.[1] Looking at the negative smiley scale, participants should report more negative emotions when being confronted with the difficult situations of both scenarios, and they should benefit from the support offered by virtual agent Pete.

Getting potentially scolded by the teacher and having the whole class look at you should create a more intensive negative reaction than the potential scolding in a situation in which everybody else is looking at a different potential perpetrator. For the Classroom scenario, we would thus find a condition effect, with reported emotions being most negative in the Participant condition, when all students are looking at the participant, and least negative in the Troublemaker condition, when all students are looking at the troublemaker. In addition, we would expect the support offered by Pete to have a positive impact (see **Figure 9** for a depiction of these anticipated results). Given the differences in the reception of social cues individuals on the autism spectrum tend to show, they might be less susceptible to the awkwardness of the ambiguous situation and thus report less negative reaction to it when all students are looking at the participant in the Participant condition. On the other hand, they might also benefit less from the support offered by Pete.

For the Cyberball scenario, being excluded in the ball games should result in more negative self-reports than being included and Pete's support should again alleviate negative reactions (compare **Figure 9**), but it is again possible that individuals on the autism spectrum might not benefit as much from the social support offered.

[1]In the pilot study on an adult sample, both a rmANOVA on the emotion reports during the three Cyberball conditions ($\eta_p^2$ = 0.64 for the negative scales) and a 2 × 2 rmANOVA on the emotion reports of the two exclusion conditions with and without support during and after the game ($\eta_p^2$ = 0.24 for timing and $\eta_p^2$ = 0.28 for the interaction) produced extremely large effect sizes. Thus, a minimum sample size for the first analysis, with a more conservatively estimated, medium effect size ($\eta_p^2$ = 0.06), two groups, a mean correlation of 0.38 between measurements taken from the pilot, a significance criterion of $\alpha$ = 0.05 and power = 0.80, would be $N$ = 34. A minimum sample size for the second was again calculated with a medium effect size ($\eta_p^2$ = 0.06), two groups, a number of four measurements, a correlation between measurements of 0.56 taken from the pilot, $\alpha$ = 0.05 and power = 0.80, resulting in $N$ = 22. 60 participants will be ample for our research goal.

The three different types of support Pete offers towards the ending of the Cyberball scenario, presence, distraction and reappraisal, are expected to differ, although results might vary, and reappraisal might be more effective for TD youth than for autistic youth (Samson et al., 2012), while the presence condition is expected to be the least effective, given that Pete is always present.

Concerning the psychophysiological measurement, with the order of the ambiguity conditions randomized and the movement of the participant restricted and reduced to potential head turns, the Classroom scenario presents a cleaner measurement situation than the Cyberball scenario. We would expect the most stressful condition, the participant condition, to induce the highest arousal, and the least stressful condition, the troublemaker condition, to induce the lowest arousal. When separating the first half of each condition from the second half ($t_{a1}$, $t_{p1}$, $t_{t1}$ from $t_{a2}$, $t_{p2}$, $t_{t2}$), expectations become less clear. Receiving support from Pete in the second half might lower arousal levels compared to the first half, but any spontaneous reactions like excitement and appreciation towards Pete, would blur this result.

The Cyberball scenario with its definite order of events does not offer the ultimate context for physiological measurements, since order effects might occur and participants move relatively often but inconsistently to catch and throw balls. Taking into account findings by Iffland et al. (2014) who worked on the physiological effects of social exclusion in Cyberball, one would expect a decrease in skin conductance level and an increase in heart rate (potentially accompanied by a decrease in heart rate variability) over the course of the three conditions.

The interpretability of these physiological results is limited, given the restrictions of the paradigm and the expectation of inconsistent movement by the participants. Still, one of the advantages of this virtual experience is that it is closer to a real-life experience and people are more physically active to play ball. The results can thus offer additional data to support the findings of the self-report measurements and act as a check on whether the experiment is indeed able to elicit emotional reactions, also on a physiological basis.

## DISCUSSION

This new VR experiment was developed to assess an aspect of social emotion regulation in youth with and without neurodevelopmental disorders, namely the impact of social support on one's self-regulation. This was achieved by creating two scenarios triggering negative emotional reactions and a virtual agent offering emotional support to help with regulation in a school environment.

Early results, including the outcome of a pilot realized with an adult sample, and insights from feedback by school-aged children and adolescents, reveal the potential of this environment for future studies. These early results were obtained after careful development of a relatively large, explorable and realistic environment, complete with a janitor robot, a class of students and a teacher, characters who can be interacted with at certain points. Participants are able to engage with the virtual world, form relationships with the relevant virtual agents and report emotional reactions through the use of smiley scales.

Results on the efficacy of virtual social support, after the induction of a negative emotional reaction, in the two samples of typically-developing and autistic youth with no intellectual disability will, firstly, inform the study on autistic traits on potential new avenues for research and training. Current research increasingly suggests reduced social motivation as a main factor in autism characteristics (Treichel et al., 2021) rather than impairment of social cognition. More detailed results about whether and how much individuals on the spectrum would accept and benefit from social regulation would inform current and future training programs on emotion regulation and social skills.

Insights on the more impactful strategies of social support, be it reappraisal, distraction or even presence only, will also help with future developments of both assessments or training. Reappraisal is the most dependent on the regulatee's understanding of the intent and content of the regulatory attempt, while presence is the least dependent. However, the simple presence of someone else, although helpful, is likely to be the least effective support given the participant's short acquaintance with regulator Pete. In any case, it is useful as a baseline condition for the other social support conditions. At the same time, presence would also be the least effortful strategy for the regulator, once the regulator is not computer-generated anymore.

This leads to a promising route for the future of this method: Having established the virtual environment as engaging and even enjoyable, and the virtual characters as socially relevant, the environment has great potential as a basis for other research programs on social emotion regulation and perhaps even in social interaction, more generally. Research paradigms could most obviously include role-reversals with participants being asked to offer support to virtual agents, thus evaluating the other side of the interaction, although many directions could be envisaged given the possibility to create different social and non-social scenarios, and integrating other possible regulation strategies offered.

While adaptations and further developments of this particular environment are possible and promising, the experiment itself also encourages virtual reality to be used more frequently as a general method in the study of social interactions and emotions. There are a number of applications for immersive virtual worlds to date in rehabilitation programs (Howard, 2017), vocational training (Bernardo, 2017; Burke et al., 2018), and also in a line of social-skill trainings for people on the autism spectrum (Parsons and Cobb, 2011). With virtual reality becoming more accessible for private households, training programs and serious games have the potential to reach a wider audience and expand the duration of their programs almost indefinitely.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Cantonal Commission for Ethics and Research, Geneva. Written informed consent to participate in this study was provided by the participants' legal guardian/ next of kin.

## AUTHOR CONTRIBUTIONS

AS, DR, LS, DD, MT, and VD contributed to theoretical conception, methodological and game design of the study. AS supervised the research, acquired funding and provided the resources. MT and VD developed the virtual environment. LS and MT conducted the assessment, curated the data and performed formal analysis. LS wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2022.826241/full#supplementary-material

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# Virtual Reality to Evaluate the Impact of Colorful Interventions and Nature Elements on Spontaneous Walking, Gaze, and Emotion

***Adamantia Batistatou, Florentin Vandeville and Yvonne N. Delevoye-Turrell****

*UMR 9193–SCALab–Sciences Cognitives et Sciences Affectives, Univ. Lille, Lille, France*

Green environments are said to have a positive impact on spontaneous physical activity and well-being. However, high quality psychological measures in natural settings are difficult to collect. In the present study, we offer a detailed report on how virtual reality may provide a controlled environment for immersive user testing. Virtual Reality (VR) was here used to test the impact of colorful floor markings on the spontaneous speed of walking, gaze behaviour, as well as perceived changes in and physiological mesures of affective states. The reactions of 36 adult participants were evaluated in Grey and Green VR environments of an urban university campus. Results in VR revealed similar results than that reported in natural settings: participants walked slower and had higher heart rates in Green than in Grey urban settings, indicating more pleasurable experiences. VR results provided nevertheless more detailed description of user experience with the possibility to quantify changes in gaze strategy as a function of the presence or absence of color designs. Spontaneous walking was slower with colorful designs than without. Gaze behaviour presented longer fixation times with colorful designs than without. Finally, physiological responses indicated that mean heart rates were similar across environments and predicted the physical effort of the task. However, greater means in heart rates were observed in the environments presenting colorful designs, suggesting that colors may be a powerful tool to trigger alertness and pleasure in Grey urban cities. Virtual reality is reported here as an innovative method to quantify psychological experiences during free exploration in gait. Applicable to a broad range of research topics in the psychological sciences, explicit guidelines are made available to share computer code and data sets for further exploitation.

**Keywords: virtual environment, gait, affective responses, restorative theory, vegetation, eye tracking, systematic representative design**

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*Laurence Chaby,*
*Université de Paris, France*

****Correspondence:***
*Yvonne N. Delevoye-Turrell*
*yvonne.delevoye@univ-lille.fr*
*orcid.org/0000-0003-4034-3684*

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## 1 INTRODUCTION

Living in the city can be unhealthy. The concrete infrastructure of a busy urban scenario plays an important role in the levels of psychological and emotional wellbeing of its citizens (Handy et al., 2002). Urban elements such as visibility (Knöll et al., 2018) and building facades (Elsadek et al., 2019) have been reported to trigger important levels of perceived stress and fatigue. Crowded streets elicit negative emotions and behaviors, which accentuate psychological stress and feelings of aggression

(Engelniederhammer et al., 2019), whereas the exposure to road traffic and noise causes physiological stress, expressed as hypertension (Bluhm et al., 2007). The simple exposition to nature may support human wellbeing. Plantations and trees (Lin et al., 2014) as well as patches of grass (Huang et al., 2020) can play a major role in restoring positive moods and affective states in concrete urban environments. Individuals report feeling more relaxed when viewing green buildings ornated with climbing plants than when looking at concrete nuded buildings (Elsadek et al., 2019). These results have convinced the general public that green elements in the built environment offer beneficial effects (Gillis & Gatersleben, 2015; Bolten & Barbiero, 2020). Unfortunately, it is not always possible to introduce nature vegetation into a built environment. Many reasons have been pinpointed, e.g., design constraints, low budgets, climate changes and lack of political decisions. Hence, city designers have been inspired to use colors to include at minima green patches of color on building walls and streets. The question remains however whether color alone is sufficient to offer the restorative effects of vegetation.

The restorative power of nature is grounded in the psycho-evolutionary theory that humans evolved in nature from the beginning of time. Thus, human beings are physiologically better adapted to live in green vegetation than in concrete environments. Green nature would have the power to lower stress levels by providing positive affective states and mild physiological arousal compared to urban human-made habitats (Ulrich et al., 1991). The innate tendency to respond positively to nature would also trigger a spontanenous state of fascination that would lead to a perception of safety (S. Kaplan, 1992). Consequently, green environments should offer a setting in which mental fatigue, attentional effort and cognitive load are minimal (Berto, 2014; Berto et al., 2014). Following these theoretical considerations, the restorative beneficits of nature should have both a physiological affective component (as stated in the stress reduction theory) and a cognitive component (as stated in the attention restorative theory).

## 1.1 Spontaneous Walking and Affective States to Test the Stress Reduction Theory of Vegetation and Color-Designs

Walking speed in the urban space has been linked to stress. Environmental elements of the urban setting can cause a feeling of anxiety or alertness that trigger an increase in walking pace. Research has shown for example that elements such as light dimming and traffic noise make walkers speed up, suggesting an increase in stress under busy urban settings (Franěk et al., 2018; Pedersen & Johansson, 2018). On the other hand, vegetation lead walkers unconsciously to slow down (Franěk, 2013). In-laboratory studies have defined the spontaneous motor tempo (or SMT) as an automatic regular sequence of movements corresponding to the preferred and natural rhythm at which an individual decides to move (Fraisse, 1982). SMT is naturally observed in daily activities, such as clapping and walking (Rose et al., 2020) and has been associated to the pace for which movement production is the easiest, providing the most pleasure (Delevoye-Turrell et al., 2014). SMT is thought to be associated directly to the physiological affective nature of the walking experience. It is a value that can capture the daily rhythm of people's lives and reveals how calm or hurried is one's walking behavior (Bornstein & Bornstein, 1976).

Affect is a psycho-physiological response that describes a broad term of feelings that a person can have, consciously or unconsciously, towards an event or a stimuli (Batson et al., 1992). Affective states have two principal dimensions. Valence characterizes the perceived quality of a stimuli as pleasant or unpleasant (Russel, 1989). Arousal indicates the physiological levels of activation associated to the stimulus at a given moment in time. In cognitive psychology, the valence is mainly quantified through self-declared questionnaires, whereas arousal can be assessed objectively through the measurement of heart rate (Wang et al., 2018). The combination of declarative and objective measurements is recommended today in the affective field of sciences for a better description of changes in users' affective states (Kondo et al., 2018).

Valence is associated to pleasantness. Urban environments such as traffic (Coensel et al., 2011) and build spaces (Berg et al., 2003; Özügner & Kendle, 2006; Wilkie & Stavridou, 2013) have been shown to impact negatively the pleasurable experience of walking. On the other hand, vegetation (Egorov et al., 2017), integrated urban vegetation (White & Gatersleben, 2011), walking in the forest (Hartig & Staats, 2006), and physical exercise in natural environments (Focht, 2009) lead to positive affective experiences. Similarly, changes in arousal have been linked to stress and many studies have reported the negative impact of concrete urban environments on emotional wellbeing. Elements such as crowd density (Fleming et al., 1987; Engel et al., 1997), urban noise (Münzel et al., 2018), and high building facades (Kalantari & Shepley, 2020) increase arousal levels. On the other hand, vegetation (Egorov et al., 2017) and green nature scenes (Ward Thompson et al., 2012) lead walkers to experience lower levels of arousal. The question is then can colors offer similar changes in affective states? A few studies in color psychology have reported that blue and green colors are linked to more positive affective states than other colors (Kaya, 2004; Savavibool et al., 2018). Ecological testing has also suggested that red triggers a significant increase whereas green decreases perceived and physiological arousal (Kutchma, 2014), which may indicate the power of colors to modulate stress levels. However, such studies are limited in number and suffer a lack of internal validity (cause-effect relationship in one condition is not forceably observed in others).

We will here test in a controlled virtual reality environment whether color-designs can offer positive affective states and decrease the speed of walking in urban settings at a similar degree than that provoked by nature green elements.

## 1.2 Gaze Behavior to Test the Attention Restorative Effects of Vegetation and Color-Designs

Following the attention theory by Kaplan, the restorative effects of nature should be associated to a strong cognitive component.

The analysis of eye blinks and movements reveal what is being looked at across time: the sky, the ground or a specific Area Of Interest (AOI) (Chevalier et al., 2010). During spontaneous walking for example, individuals show distinct gaze strategies appropriate for the demands of different terrains, and this information can be used to characterize the cognitive load and mental fatigue associated to navigation (Matthis et al., 2018). Gaze patterns reveal both active exploration and passive detection, which are key processes when trying to understand human-environment interaction (Colombo, 2001). Hence, by quantifying eye blink frequency, gaze direction and fixation duration, it is possible to model the cognitive component of spontaneous motor behavior both in laboratory and real-world testing.

Blinking is the involuntary reflex of opening and closing the eyes (Volkmann et al., 1982). Blink rate varies systematically in cognitive tasks such as reading, talking and video watching (Fukuda, 1994; Himebaugh et al., 2009). This is typically attributed to variations in cognitive load (Orchard & Stern, 1991). Despite evidence for some systematic variation with dopamine level, blinking is universally regarded as epiphenomenal, rather than functional. Much more research has been conducted on gaze control. Gaze direction in the urban space has been linked to "journey fixation". During free walk, participants with normal vision direct their gaze primarily straight ahead targeting a goal (Turano et al., 2001). Furthermore, the complexity of the walking surface (Matthis et al., 2018) as well as the density of circulation (Trefzger et al., 2018) modulate systematically gaze direction and lead it to focus more frequently towards the ground.

The duration of gaze fixations is predicted in the urban space by the levels of interest given to an object. Environmental elements placed in an urban scenery may increase alertness, which also tend to increase fixation duration because of an augmented focus of attention to interesting/meaningful/threatening elements (Leveque et al., 2020). Indeed, crossroads and traffic lights increase duration of fixations (Fotios et al., 2014; Biassoni et al., 2018). On the other hand, grass (Egorov et al., 2017) and nature scenes (Ward Thompson et al., 2012) lead walkers to decrease the number and duration of fixation points. Nevertheless, it is unclear whether these effects are due to the nature per se or to the color patches. Indeed, in the field of cognitive psychology, perceptual studies have reported that people scored more fixations in counts and in duration when presented with their preferred colors, which sometimes included the color green (Lee et al., n.d.).

In the present study, we questioned how colorful designs in the urban environment could influence gaze strategies. Using a virtual reality headset with an integrated eye-tracker, we report the number of blinks per minute to quantify changes in cognitive load. Gaze direction and fixation durations were also measured to test the attention restorative effects of vegetation and color-designs.

## 1.3 Paradigm Shift in Experimental Design to Model the Effects of Colorful Interventions

Paint is a flexible intervention tool applicable to urban architectures as it is ephemeral and non-invasive. Colorful floor markings have been used as design solutions in re-zoning urban spaces and guiding pedestrians. Colors are indeed an essential visual factor of the environment (Jalil et al., 2012). Empirical observations have reported the impact that colors may have on walking perception and behavior. For example, runners with red T-shirts were perceived as running faster than those wearing blue T-shirts (Mentzel et al., 2019). Pedestrians were reported to walk faster when presented with red stimuli compared to trials for which blue stimuli were used (Meier et al., 2012). These results echo the empirical data that have been reported for decades during color walks: color is a key solution to improve walking experience and pleasure in the city (Evans, 2019). Nevertheless, little quantification has been reported. Even with the advances of wearable technology, testing in natural habitats remains complicated with difficulties associated to data collection, limits in replicability (e.g., weather dependency) and the absence of baseline controlled conditions.

Virtual reality (VR) has made its entry in psychological testing by offering a solution to the traditional trade-off between control and generalization: (1) in lab protocols to provide systematic manipulations of the visual displays vs. (2) the use of naturalistic whole-body tasks to augment transferability in more natural organism-environmental conditions. VR is a paradigm shift in experimental design as it offers the means to present systematic representative designs while quantifying changes in human behavior and experience (Miller et al., 2019). In the present study, we report the use of VR as a method to test the impact of color and vegetation on pedestrian walking in an urban environment, while factoring in both the cognitive load and the emotional experience of the task. Physiological and behaviarol parameters (walking speed; gaze behaviors) were collected during free exploration of an urban university campus; questionnaires were included in a pre-post design procedure. The question was specifically to assess whether color patterns can offer similar positive restorative effects than vegetation in urban spaces. The following hypotheses were formulated:

H1: (a) Urban vegetation will be perceived as more pleasant than urban concrete. (b) Perceived pleasantness will be greater in urban concrete with color-designs than without.
H2: (a) Alertness and heart rate will be reduced in urban vegetation compared to urban concrete. (b) Color-designs will decrease aleterness and thus, lower heart rates will be observed in urban concrete with color-designs than without.
H3: (a) Speed of walking will be reduced in urban vegetation compared to urban concrete. (b) Speed of walking will be lower in urban concrete scenes with color-designs than without.
H4: Blink rates will be lower in urban concrete than in urban vegetation.
H5: (a) Gaze will be directed less frequently towards the ground in urban vegetation than in urban concrete. (b) Frequency of gaze towards the ground will be lower in urban concrete with color-designs than without.
H6: (a) Number of gaze fixations will be lower in urban vegetation than in urban concrete. (b) Number of gaze

fixations will be lower in urban concrete with color-designs than without.

## 2 METHODS

### 2.1 Participants

Young healthy adults were recruited from amongst the corpus of staff and students at the University of Lille. All participants had normal to corrected-to-normal vision, and did not present motor dysfunction, neurological/psychiatric disorders or colorblindness. Each participant provided written informed consent and demographic information (sex, age, and VR expertise) before coming to the laboratory to participate in a unique experimental session lasting 90 min. This protocol is registered by the CNIL for good management of human personal data (GED UnivLilleN1-201816).

A within-subjects design was applied wherein each condition was performed in a semi-randomized order. The sample size required for the present study was calculated using G*Power (3.1.9.2). The walking speed data of Franek et al. (2018) were used as group parameters and the power analysis indicated that a total of 32 participants was required for walking speed (f = 0.417; $\alpha$ = 0.05; 1-$\beta$ = 0.80). The gaze data of Matthis et al. (2018) were used as group parameters and the power analysis indicated that a total of 18 participants was required for fixation duration (f = 2.565; $\alpha$ = 0.05; $1 - \beta$ = 0.80). Accordingly, a sample of 35 individuals (16 males, 19 females; mean age = 23.59 ± SD = 8.79: 18–51 years) was recruited to guard against technical failure.

**FIGURE 1 |** Picture of a typical participant performing the walking on the SPOT task. Breaks were taken between trials to limit nausea as the task required continuous movement.

### 2.2 Materials

#### 2.2.1 Task and Visual Environments

The task was to wear a virtual reality (VR) helmet and to step-on-the-spot while discovering different versions of an urban university campus. We decided to use a minimalistic representation of the main library campus to favor the focus of attention of the participants on the effects of color and vegetation. All participants were familiar with the true University grounds and buildings, and the identical minimalistic representation was used across the six experimental trials. Each participant was invited to take their time to discover the library environment by following a pathway that appeared in front of them. Depending on the condition, the landscape displayed buildings and grey sidewalks or the same buildings set within a green environment that included plantations such as trees and large patches of grass. The path to follow was a painted line, which was white or colored (red-green-blue). Finally, colorful designs could be displayed upon the path. Hence, each participant walked around the university library six times in seperate trials, characterized by specific ambiances. During the VR task, participants were asked to stand on a textured mat to help maintain body stability during the stepping-on-the-spot task (**Figure 1**). Hence, at the start of the session, participants were invited to take their shoes off. Participants moved continuously, which is know to cause nausea (Birenboim et al., 2019). Air conditioning was used to maintain the temperature of the room at a constant 19.5°, to prevent overheating and sweating during stepping. Between the 15-min trial runs, 5-min breaks were taken to limit the emergence of nausea. During this break, participants were invited to sit and take the VR helmet off. For all participants, the Simulator Sickness Questionnaire was administered at the end of each trial in order to gain a self-declared description of the degree of simulator sickness experienced. The scale is from 1: no nausea; 4: severe nausea. In the present study, nausae levels was scored at 1.50 (1.2–1.8), confirming the absence of nausea across trials.

Unity code was used to create the virtual replication of the University campus grounds. In the Concrete urban environment, there were no green elements, only buildings. In the Vegetation urban environment, grass and trees were included using different shades of green. The trees were placed far from the path to avoid the perception of the trees as obstacles. In both types of environments, a total of three design scenarios were tested as floor markings. The path was (1) a white line (control), (2) a line painted in three RGB colours (red, blue or green) and (3) color designs embedded within the RGB line. The position and size of the designs were randomized between participants. Illustrations of the VR environments are provided in **Figure 2**.

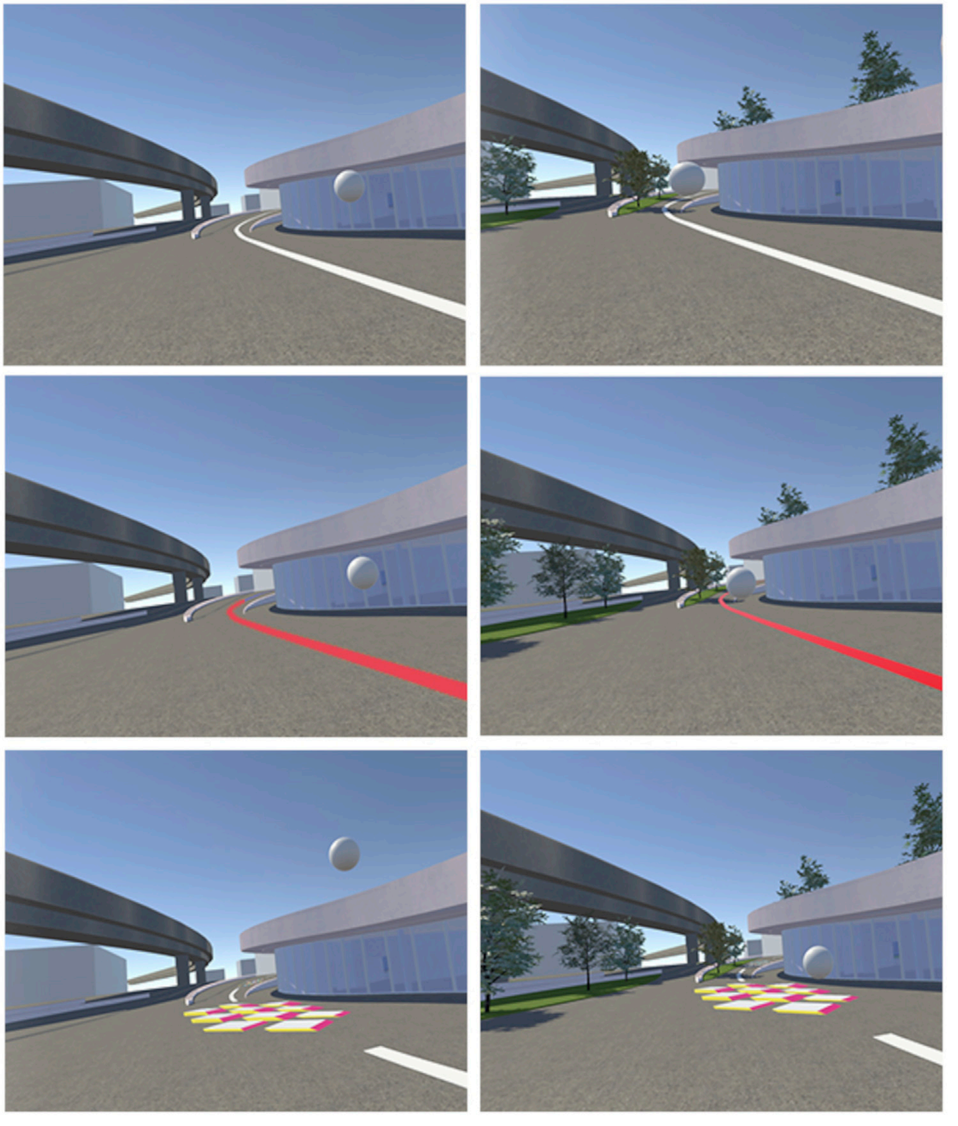

**FIGURE 2 |** Illustration of the six virtual environments that were created using UNITY. The protocol provided the means to evaluate the impact of color visual environments on user experience. Top row = no color floor marking; Middle row = RGB color lines (red, blue, green); Bottom row = RGB colors embedded in playful designs.

### 2.2.2 Virtual Reality System and Eye Tracking

The virtual reality HTC Vive was used. The light-weight headset displayed visual environments with a resolution of 1,080 × 1,200 pixels per eye for a 110°field of view. The refreshing rate was 90 Hz. The HTC Vive headset was implemented with an eye-tracking system from Senso Motoric Instruments (SMI) that recorded gaze position and movement of both eyes at a rate of 250 Hz. The HTC Vive comes with a ensemble of sensors that capture behavioral changes during user testing (accelerometers, gyroscopes, proximity sensors).

In the present study, two vive controllers were used to offer the participant the possibility to interact and move freely in the VR environment. Held in both hands, the user pressed the trigger buttons and was required to maintain the light pressure on these triggers throughout the exploration. Then, she/he could swing the arms to move forward in the direction in which the controllers were pointed. The speed in the virtual environment depended on the speed of arm swing. Two vive base stations were placed 4 m away from the participant and tracked the vive controllers to create a 360°virtual space. This virtual "room scaled" environment offered a space in which the user could walk fast and slow, stop and interact (e.g., touch a leaf or the building walls). The speed scale was set to high. Thus, the true mean speed of spontaneous arm swing during stepping was in fact 15–20% slower than that presented in the VR environment. The vive base stations detected the 3D position of the helmet. This information

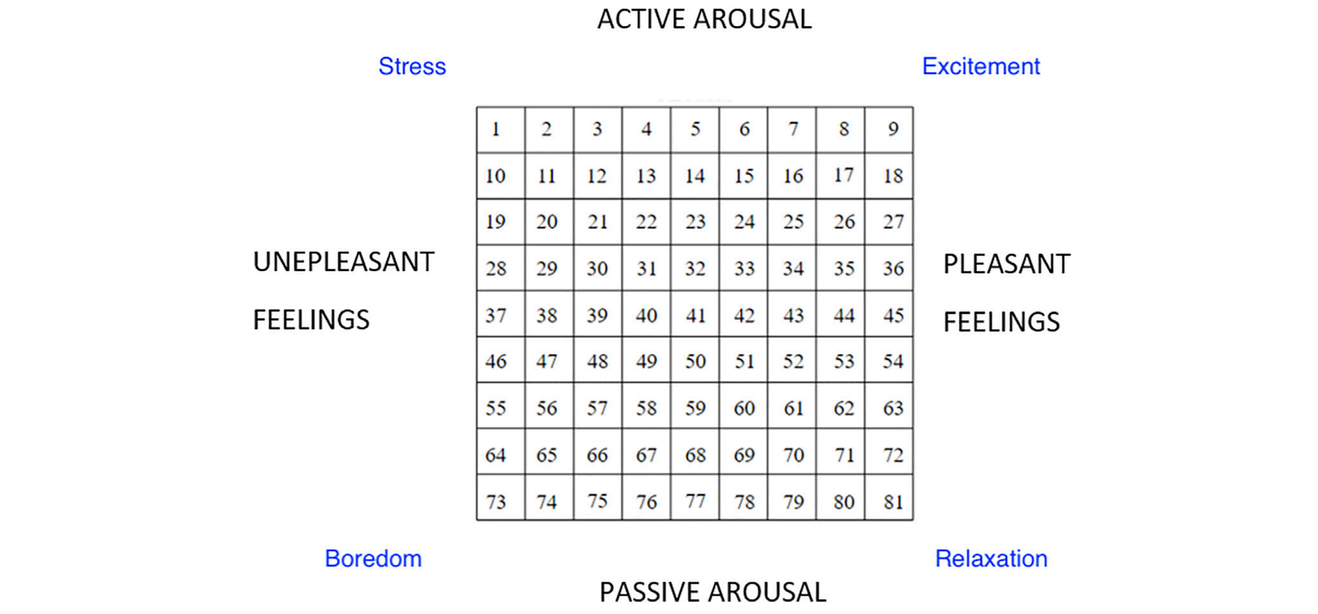


**FIGURE 3 |** Illustration of the numerical grid used to self-guide the evaluation of an individual's affective state at a given moment in time.

was used to measure gaze direction. All tracking was performed with infrared pulses set at 60 Hz.

#### 2.2.3 Objective Measure and Declarative Evaluation of the Affective States

The Empatica E4 wristband (Empatica S.r.l, Milano, Italy) is a portable wristband that provides real-time physiological data streaming and visualization. It records photoplethysmographic data, temperature and electrodermal activity. In the absence of cables, it offers free movement and accurate measurements of cardiac responses (Richardson et al., 2020). Heart Rate (HR) means were calculated from the pulse peak intervals and are reported in beats per minutes (BPM). All signal processing steps were performed using the python's package HeartPy (van Gent et al., 2018; van Gent et al., 2019). A third order band-pass Butterworth filter was applied with cutoff frequencies of 0.7 and 3.5 Hz. Before filtering, the matrix of pulse intervals was cleaned for outliers by applying the interquartile range method.

Within the current models of emotion, affect is a neuro-physiological state that is always present and can arise to consciousness by voluntary re-orientation of attention (Barrett & Bliss-Moreau, 2009). Hence, the use of a self-evaluating grid can help guide individuals to gain an insight on interior states of emotion (Brossard & Delevoye-Turrell, 2022). The self-declared affective experiences were collected with the Feeling and Affect Table to score Arousal and Appraisal (**Figure 3**). The FAtAAL is a 2-dimensional digital grid that is adapted from the Russell grid for Affective States (Russel, 1989). Implemented within the VR scene at the end of the trial, the 18-by-18 bingo grid guides a participant to evaluate her/his affective state, considering at the same time both the intensity (arousal) and the pleasantness (valence) of an experience. A simple number verbalized by the participant is sufficient to code the affective state at a given moment in time.

## 2.3 Design and Measures

Participants were encouraged to engage in a spontaneous and natural walking-on-the-spot movement during free exploration. A military sort of stepping movement was encouraged to have participants swing arms during body movement. Objective measures were collected throughout the unique session to characterize tempo of spontaneous gait, gaze strategy and affective states (**Figure 1**). Self-declared questionnaires were administered at the end of each trial to limit interfering with user experiences.

### 2.3.1 Spontaneous Walking Behavior

The time spent exploring each environment was measured in seconds as the duration of a trial. This time interval was calculated as the difference between the first moment participants stepped on the path and the instant they reached the end of the path. The number of stops was counted as the number of times participants released the triggerbutton of one of the two controllers. The mean duration of a trial in seconds and the mean number of stops are reported for each participant and condition.

Walking speed was extracted from the relative 3D coordinates of the headset, every 200 ms. The total distance for a trial was calculated by summing the vectorial distance of each frame. The average speed was then calculated in m/s and converted in km/h, for each participant and condition.

### 2.3.2 Gaze Behavior

The SMI eye-tracking system recorded gaze position and direction. The 9-point calibration procedure was performed before the start of each session. It provided the means to scale the visual environment as a function of the morphology of each participant.

The absence of eye tracking recordings at a given moment coded for the presence of an eye blink. After the detection of a possible eye blink, a time interval of 100 ms was applied before searching for the next event, as the minimum duration of a blink is 100 ms (Schiffman, 1990). Mean number of eye blinks was calculated for each participant and condition as an indicator of cognitive load.

Gaze direction was grouped in three distinct categories. Participants were considered to be looking straight ahead if their gaze remained within a range of 20°, centered around the horizontal gaze line (calculation based on the dot product–see supplementary data). The number and duration of fixation points higher, lower and around the horitonal gaze line were calculated for each participant and condition.

Gaze fixations were extracted using the MATLAB toolbox, EyeMMV (Krassanakis et al., 2014). Specifically, the XY coordinates were measured at each recording frame and averaged across both eyes. The EyeMMV algorithm relies on a two-step spatial dispersion thresold. Detection is then extracted to determine number of fixations and mean duration of fixation, for each participant and condition.

The VR environment was tagged with imaginary areas of interest (AOI). The AOI were locations in which the colorful designs could be present, i.e., they were present in the color-design conditions but absent in all other conditions. To gain an insight on the role played by color visual environments on gaze behavior, the mean number and duration of AOI fixations were calculated for each participant and condition.

## 2.4 Affective States

Self-declared affective states were collected using the FAtAAL grid. The levels of arousal and valance were calculated by converting each 9-point Likert-type scale with anchors coding for 1 = unpleasant, and 9 = pleasant feelings on the valence x-axis, and for 1 = active arousal, and 9 = passive arousal on the y-axis. A score above six on the valence scale indicated positive affective states. A score above six on the arousal scale indicated relatively high levels of perceived arousal.

Heart rate is an objective indicator of physiological arousal. Baseline levels were claculated during rest, for a total of 2 min when participants were seated. Then, during each trial, the mean HR was calculated during the two last minutes of each trial. Mean delta HR was calculated for each participant and condition.

## 2.5 Procedure

### 2.5.1 Welcome Phase

Upon arrival at the laboratory, the participant was asked to read and sign a consent form. The study was conducted in a large and quiet room, without windows. Care was taken to clear the area from any obstacles to provide a comforting and reassuring user experience. Participants were invited to put the VR helmet on, and to take a few minutes to get familiarized with the VR setup while performing the walking task, using the arms to navigate in the VR environment. For this familiarization phase, participants were immersed in a green neighborhood outdoor basketball court.

### 2.5.2 Baseline Phase

Before the start of the session, each participant was invited to sit for 4 min to relax. This was important in order to obtain two types of baseline (resting and stressor baselines) that would then be used to compute relative physiological reactions to the green or colorful visual environments.

After sitting calmly for 4 min, participants were invited to put the VR helmet on, and the resting baseline was taken during 3 min. Participants were then invited to engage in a series of mental calculation tasks that consisted in counting backwards from a random four-digit number, in steps of a random two-digit number. The participant was informed of the following: "You will be monitored carefully during the tasks by the research staff and a buzzer will sound every time you give an incorrect answer." At the end of the mental calculation tasks that lasted 90 s, the stressor baseline was taken for 3 min (Dedovic et al., 2005; Al-Shargie et al., 2016).

### 2.5.3 Experimental Phase

After the baseline phase, participants were invited to stand and place their feet in the center of the mat. Participants were encouraged to engage in a gait pattern that was spontaneous and easy, to walk at their preferred pace, on-the-spot, while moving the arms naturally and freely. At the end of the exploration time, participants answered the FAtAAL grid, took the helmet off, and sat down to relax for 4 min by concentrating on their breathing. During pre-testing, these pre-set break times were found to be efficient in limiting the emergence of discomfort and nausea.

When ready to start the experimental trials, participants were invited to put the helmet on to record the 2-min HR baseline while remaining seated. Then, with the experimenter's help, the participant stood and engaged in the trial. At the end of block 6, participants received a detailed debriefing of the general objectives of the study and was thanked for her/his time.

## 2.6 Data Processing and Statistical Analyses

Data processing and analyses were performed with personal code written in Python, which can be made available upon request (see Supplementary Data 2). The experiment was composed of 1 block of six trials. Classic null-hypothesis significance tests were applied to reveal the effect of Environment and Condition on the user experience. A two-way repeated measure ANOVA was conducted with Environment (Urban Concrete; Urban Nature) and Condition (White-line, Color-line, Color-design) as the two independent factors. The probability level was set to 0.05 for test interpretation. Partial etas squared ($\eta_p 2$) were calculated to report effect sizes. Pairwise t-tests were computed when ANOVA was significant and were adjusted for multiple comparisons using Holm-Bonferroni corrections.

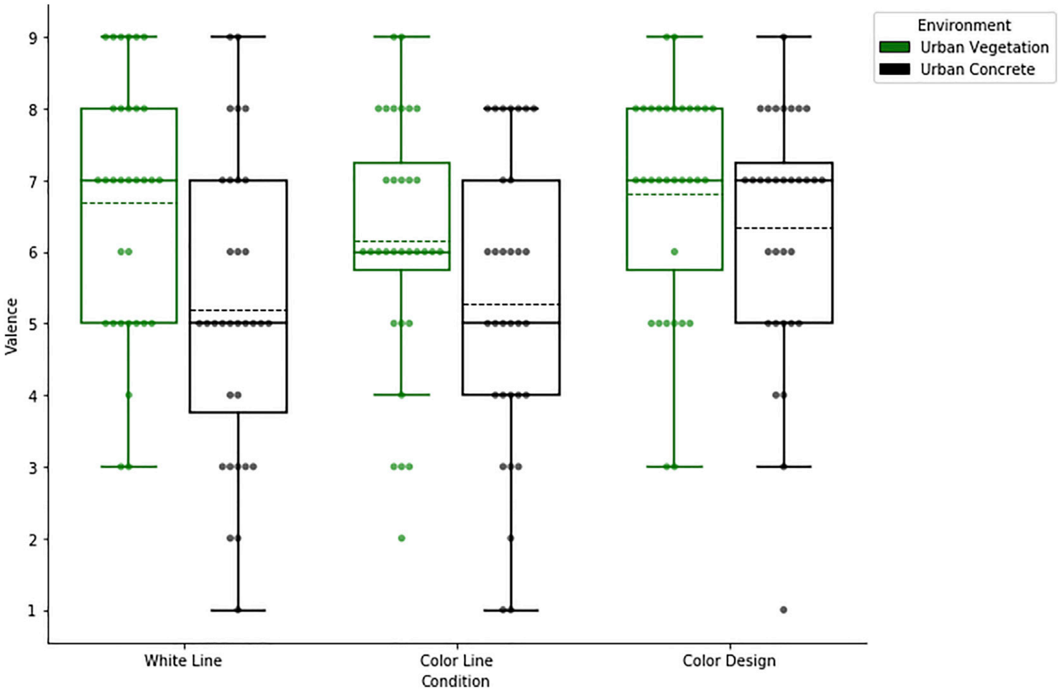


**FIGURE 4 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) and Condition (White Line; Color Line; Color Design) on the valence dimension of the FAtAAL grid, which reports the perceived pleasure experienced during spontaneous walking in the six different urban virtual environments.

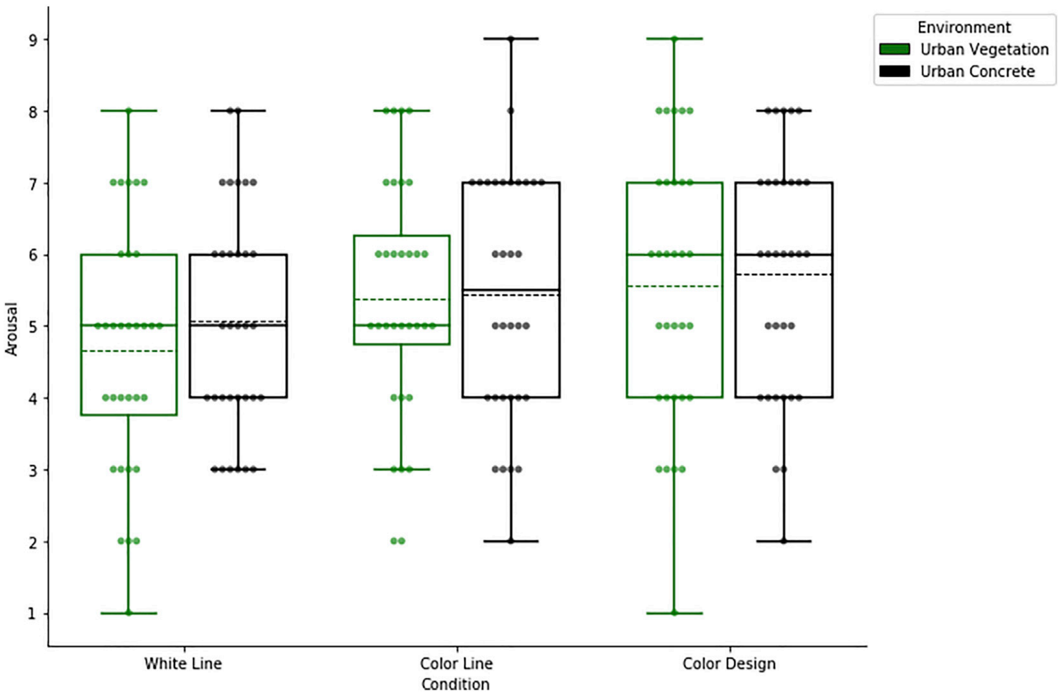


**FIGURE 5 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) and Condition (White Line; Color Line; Color Design) on the arousal dimension of the FAtAAL grid, which reports the perceived alertness experienced during spontaneous walking in the six different urban virtual environments.

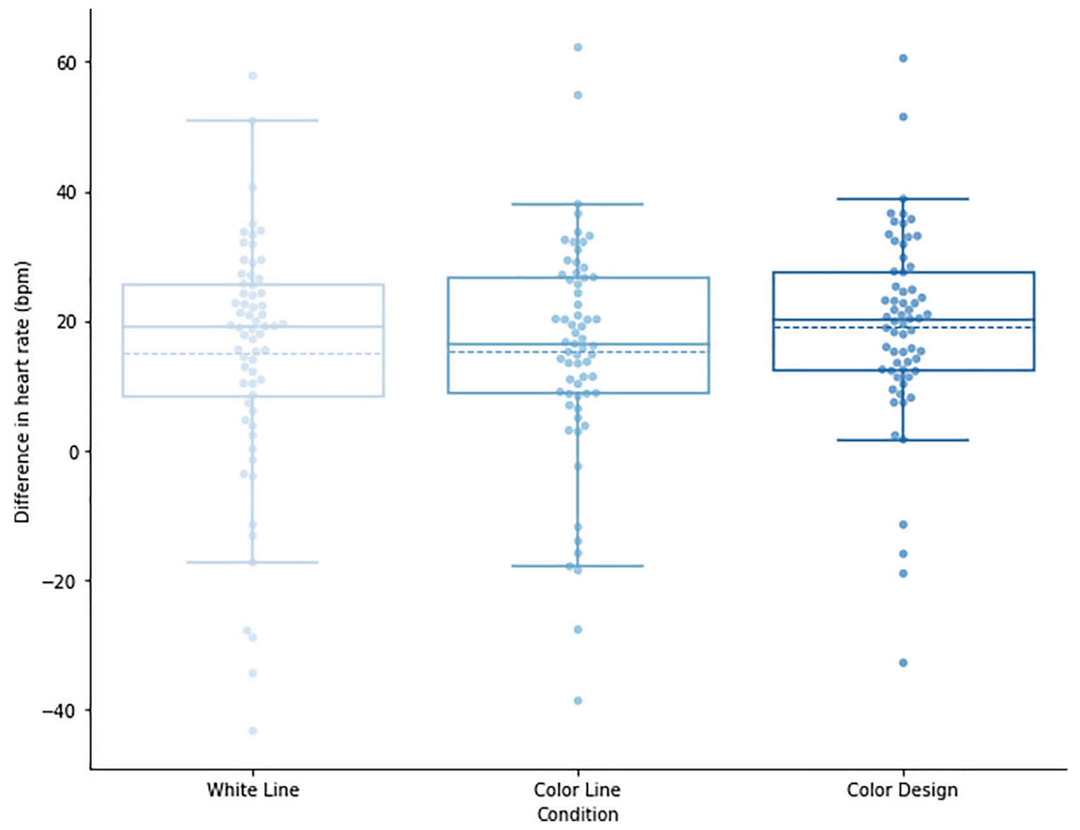


**FIGURE 6 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) on the physiological changes in heart rate during spontaneous walking in the three urban virtual environments.

# 3 RESULTS

## 3.1 Emotional Responses

The Empatica E4 wristband and the FAtAAl grid provided the means to collect the objective and perceived changes in affective states. Results test H1 and H2 and are presented in **Figures 4–6**.

### 3.1.1 Perceived Valence and Arousal

The two-way ANOVA revealed a signficant main effect of Environment for valence, F (1,31) = 12.38, $p$ = 0.001, $\eta_p 2$ = 0.29, with higher scores in Urban Vegetation (M = 6.55, SD = 1.70) than in Urban Concrete (M = 5.60, SD = 2.01). There was also a main effect of Condition, F (2, 62) = 4.16, $p$ = 0.02, $\eta_p 2$ = 0.12, with higher scores in Color Design (M = 6.58, SD = 1.64) than in White Line (M = 5.94, SD = 2.05) and Color Line conditions (M = 5.72, SD = 1.96). Post hoc tests confirmed the differences between Color Design and Color Line ($p$ = 0.001). The interaction effect was not significant, F (2,62) = 2.16, $p$ = 0.12.

The two-way ANOVA revealed a signficant main effect of Condition for arousal, F (2,62) = 5.03, $p$ = 0.001, $\eta_p 2$ = 0.14, with lower scores in White Line (M = 4.86, SD = 1.65) than in Color Line (M = 5.41, SD = 1.70) and in Color Design conditions (M = 5.64, SD = 1.79). Post hoc tests confirmed the differences between Color Design and White Line ($p$ = 0.001). Both the main effect of Environment, F (1,31) = 0.86, $p$ = 0.36, and the interaction effect were none significant, F (2,62) = 0.39, $p$ = 0.68.

### 3.1.2 Changes in Heart Rate

The two-way ANOVA revealed a signficant main effect of Condition on the changes in HR, F (2,62) = 4.22, $p$ = 0.02, $\eta_p 2$ = 0.12, with higher scores in Color Design (M = 19.09, SD = 14.94) than in White Line (M = 14.99, SD = 18.59) and in Color Line conditions (M = 15.43, SD = 17.37). Post hoc tests confirmed the differences between Color Design and the other conditions ($p$ = 0.04). The main effect of Environment was none significant, F (1,31) = 0.60, $p$ = 0.45, as well as the interaction effect, F (2,62) = 1.01, $p$ = 0.37.

## 3.2 Walking Behavior

Results in this section test H3 and are presented in **Figure 7**.

### 3.2.1 Number of Stops

The two-way ANOVA on the number of stops revealed an absence of main effects of Environment (F (1,31) = 0.17, $p$ = 0.68) and Condition (F (2,62) = 1.65, $p$ = 0.20). The interaction effect was not significant (F (2,62) = 0.03, $p$ = 0.97). On

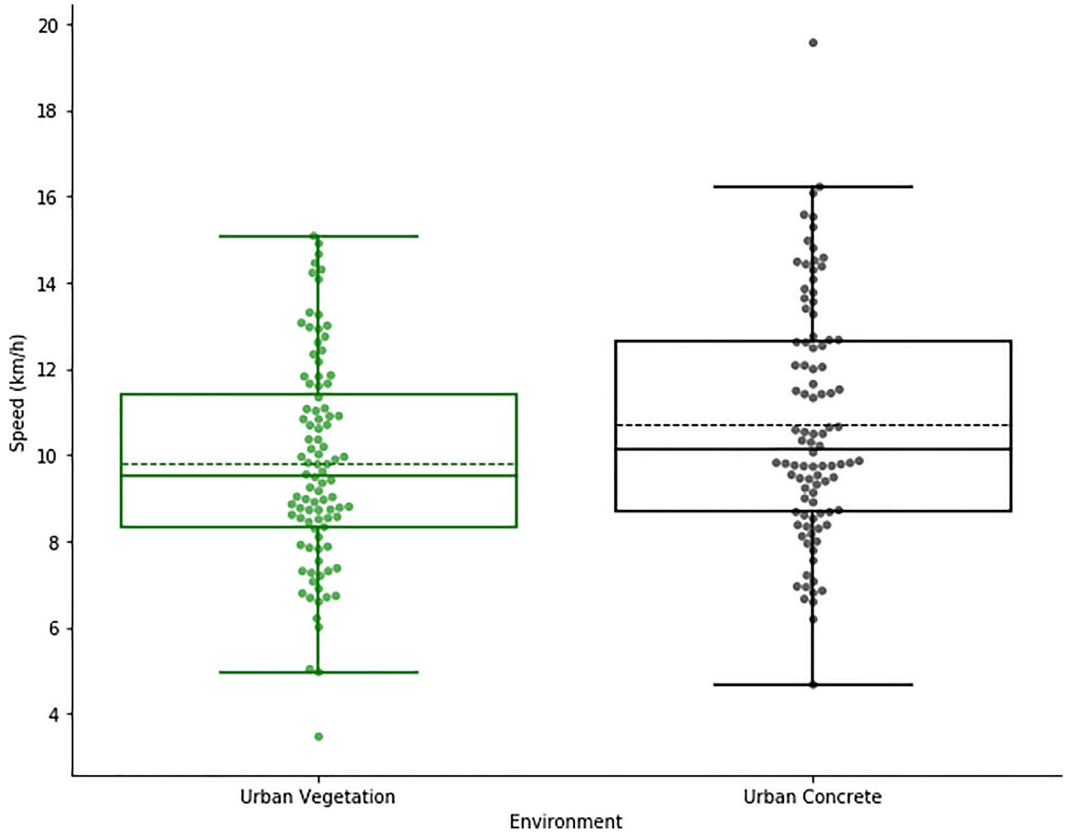


**FIGURE 7 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) on the speed of spontaneous walking in the two urban virtual environments.

average, participants stopped 1.791 times during the course of a trial (min = 0; max = 9).

### 3.2.2 Walking Speed

The two-way ANOVA revealed a signficant main effect of Environment on the speed of spontaneous walking, F (1,31) = 14.16, $p < 0.001$, $\eta_p 2 = 0.31$, with higher scores in Urban Concrete (M = 10.73, SD = 2.76) than in Urban Vegetation (M = 9.78, SD = 2.41). There were no main effects of Condition, F (2,62) = 2.82, $p = 0.07$, and the interaction effect was not significant, F (2,62) = 0.80, $p = 0.45$.

## 3.3 Gaze Behavior

The eye-tracking system that was integrated within the HTC Vive helmet provided the means to characterize gaze strategies through the measurements of blink rates and gaze direction. These results test H4 and H5. Results are presented in **Figures 8**, **9**. To test H6, we quantified the number and duration of gaze fixations overall but also specifically to the AOIs. These results are presented in **Figures 10**, **11**.

### 3.3.1 Blink Rates

The two-way ANOVA revealed an absence of main effects of Environment (F (1,31) = 0.10, $p = 0.75$) and Condition (F (2,62) = 0.47, $p = 0.63$). The interaction effect was also not significant (F (2,62) = 0.37, $p = 0.69$) for the number of eye blinks per minute (M = 14.78, SD = 9.81, min = 2.59, max = 41.86).

### 3.3.2 Gaze Direction

The two-way ANOVA revealed a signficant main effect of Environment on the proportion of time spent with gaze direction toward the horizon, F (1,31) = 5.35, $p = 0.03$, $\eta_p 2 = 0.15$. Results indicated higher scores in Urban Vegetation (M = 75.88, SD = 18.57) than in Urban Concrete (M = 72.85, SD = 20.38). The main effect of Condition was not significant, F (2,62) = 1.31, $p = 0.28$. However, the interaction was significant, F (2,62) = 3.96, $p = 0.02$, $\eta_p 2 = 0.11$, indicating that the differences between Urban Concrete and Vegetation environments were only verified in the White Line and Color Line conditions.

The two-way ANOVA revealed a signficant main effect of Environment on the proportion of time spent with gaze direction towards the ground, F (1,31) = 6.11, $p = 0.02$, $\eta_p 2 = 0.16$. Results indicated lower scores in Urban Vegetation (M = 22.54, SD = 18.76) than in Urban Concrete (M = 25.93, SD = 20.7). The main effect of Condition was not significant, F (2,62) = 1.38, $p = 0.26$. However, the interaction was significant, F (2,62) = 4.23, $p = 0.02$, $\eta_p 2 = 0.12$, suggesting that the differences between Urban Concrete and Vegetation

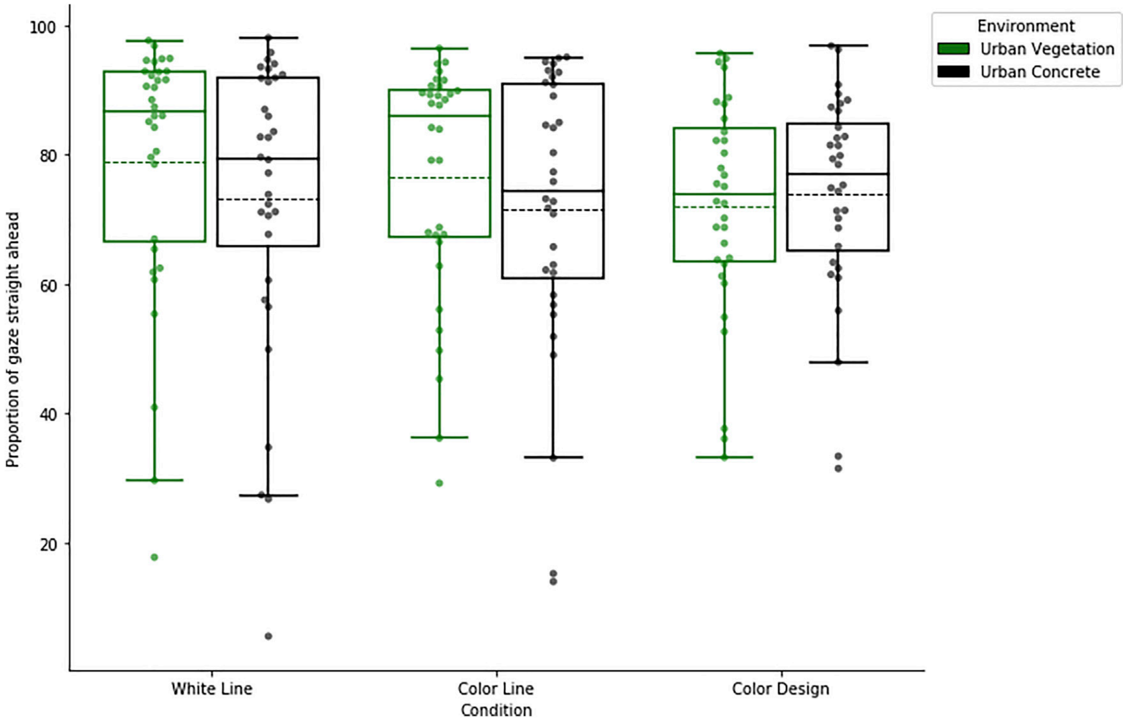


**FIGURE 8 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) on the proportion of time spent looking straight ahead during spontaneous walking in the six urban virtual environments.

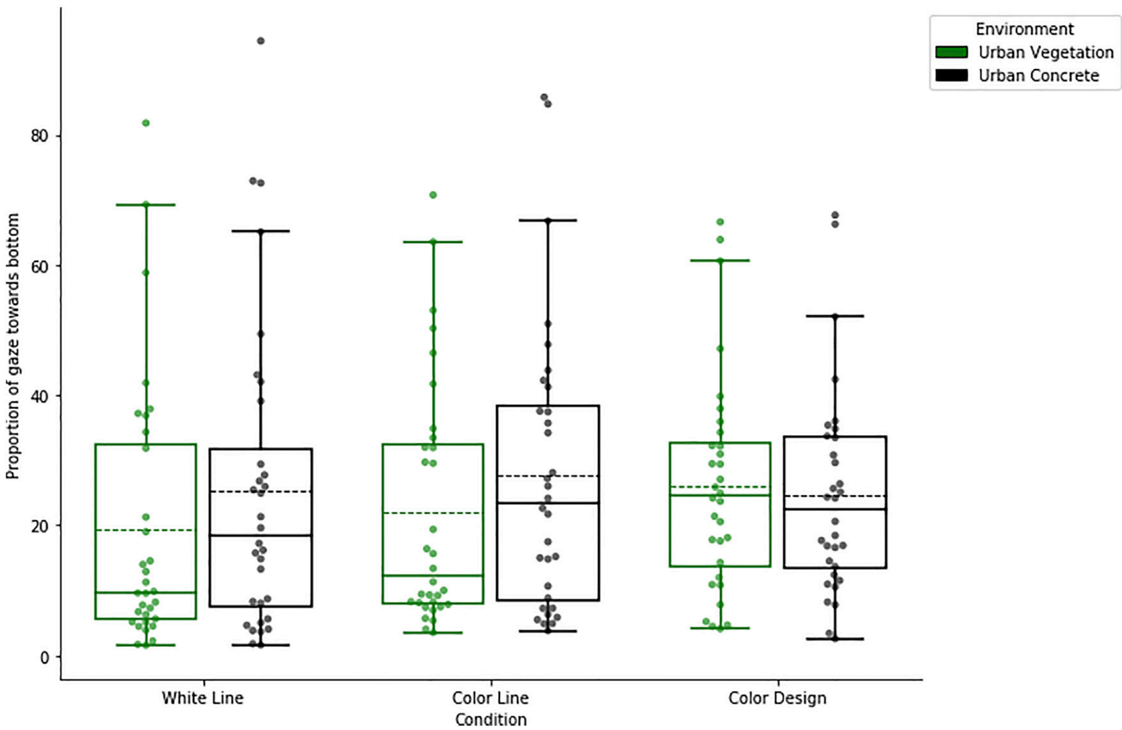


**FIGURE 9 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) on the proportion of time spent looking towards the ground during spontaneous walking in the six urban virtual environments.

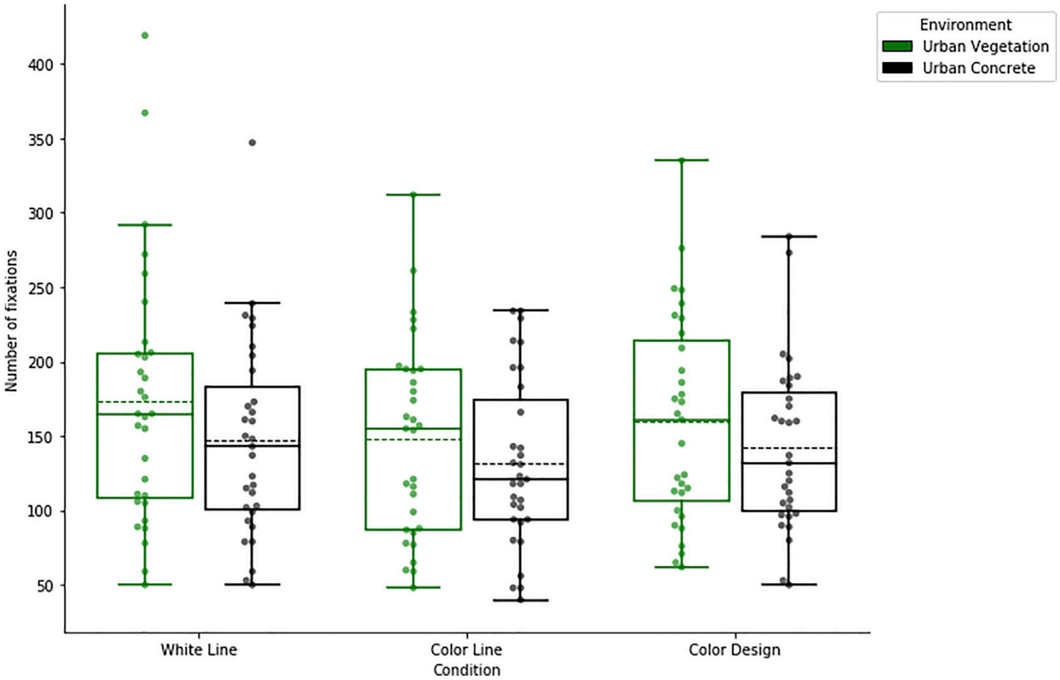


**FIGURE 10 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) on the number of gaze fixations during spontaneous walking in the six urban virtual environments.

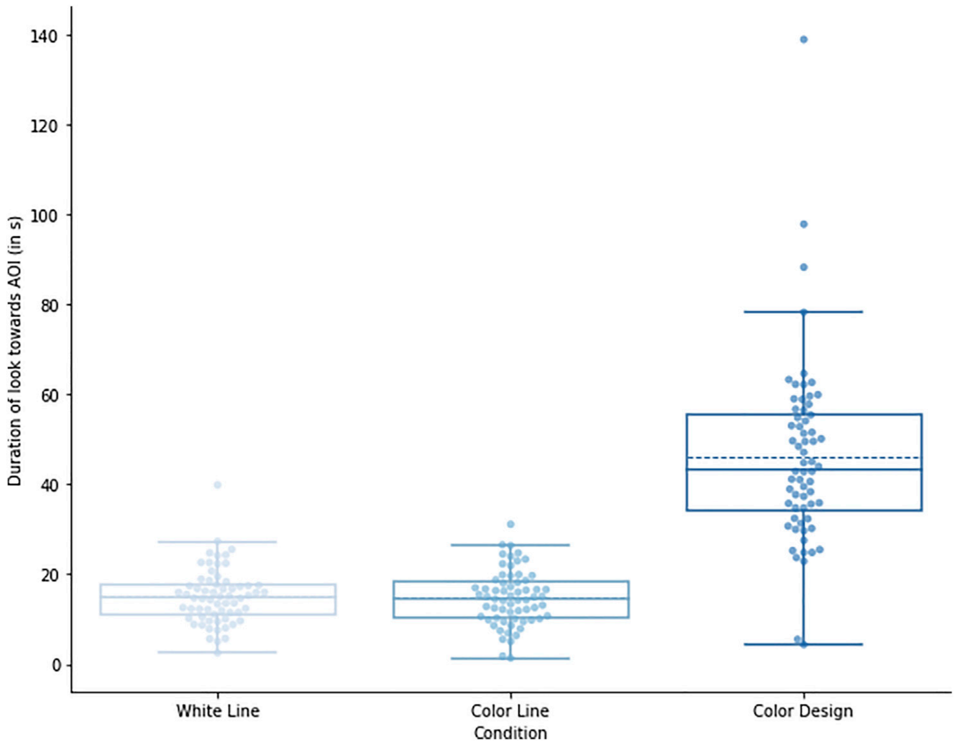


**FIGURE 11 |** Bar charts illustrating the impact of Environment (Concrete *vs*. Vegetation) on the duration of gaze fixations to the areas of interest (AIO) during spontaneous walking in the six urban virtual environments.

environments were only verified in the White Line and Color Line conditions.

## 3.4 Number and Duration of Gaze Fixations

The two-way ANOVA revealed a signficant main effect of Environment on the number of fixations, F (1,30) = 8.87, $p$ = 0.006, $\eta_p 2$ = 0.23, with higher scores in Urban Vegetation (M = 160.29, SD = 74.27) than in Urban Concrete (M = 140.33, SD = 59.65). The main effect of Condition was also significant, F (2,60) = 3.18, $p$ = 0.049, $\eta_p 2$ = 0.10, with higher scores in White Line (M = 160.05, SD = 76.89) than in Color Line (M = 139.71, SD = 61.81) and Color Design (M = 151.18, SD = 63.6). The interaction was not significant, F (2,60) = 0.28, $p$ = 0.76.

The two-way ANOVA on duration of fixation indicated an absence of main effects of Environment (F (1,30) = 0.04, $p$ = 0.84) and of Condition (F (2,60) = 2.85, $p$ = 0.07). The interaction effect was not significant (F (2,60) = 0.14, $p$ = 0.87). When considering specifically the gaze fixations to AOIs, the results on gaze fixation duration revealed a signficant main effect of Condition, F (2,62) = 112.72, $p$ < 0.001, $\eta_p 2$ = 0.78, with higher scores in Color Design (M = 46.12, SD = 20.41) than in White Line (M = 15.09, SD = 6.26) and Color Line conditions (M = 14.77, SD = 6.11). Post hoc tests confirmed the difference between Color Design and the other conditions ($p$ < 0.001). Neither the main effect of Environment, F (1,31) = 0.15, $p$ = 0.71, nor the interaction effect were significant, F (2,62) = 0.28, $p$ = 0.75.

# 4 DISCUSSION

Virtual reality (VR) is the use of computer technology to create a simulated environment. The benefits of VR testing for cognitive science have been discussed in thorough theoretical papers (Miller et al., 2019). By combining physiological and behavioral measures during spontaneous walking, we present novel data confirming that VR can help tackle the key question of whether color design can mimic the beneficial effects of nature on human spontaneous motor behavior and wellbeing.

## 4.1 Stepping-On-The-Spot to Mimic Spontaneous Walking

Our first aim was to report data and scripts that describe the psychological experiences of human users in an ecologically-valid behavioral task. We considered the difficulty in choosing the natural behavior of walking. VR studies have used different tasks to simulate walking in VR environments: joy-stick clicking, arm-swing, stepping-on-the spot. These approaches will never offer the exact same experience than true walking in 3D space (Nilsson et al., 2016). Nevertheless, the stepping-on-the-spot task has been reported to offer a good experience of immersion (Nilsson et al., 2013a) with better performance levels in orientation tasks than that observed when using joystick controllers (McCullough et al., 2015) or arm-swing (Wilson et al., 2013). The stepping task is also more realistic, with levels of perceived effort greater than that reported for arm-swing (Nilsson et al., 2013b; Pai & Kunze, 2017) and thus, more similar to that reported during real-world walking. Hence, we selected the stepping-on-the-spot task to assess whether green elements can promote similar changes in a virtual environment than that observed in natural settings.

## 4.2 Walking in Green VR Environments

Natural elements such as green landscapes have a calming effect on physiological arousal (An et al., 2016). One of the long-term effects of access to nature is a positive attitude towards life and an increased satisfaction with one's own home, one's own work and generally one's own life (R. Kaplan, 2001). Our VR data confirmed that urban vegetation was perceived as more pleasant than urban concrete environments (H1a confirmed). Speed of walking was reduced in urban vegetation compared to urban concrete (H3a confirmed) confirming previous ecological data (Franěk et al., 2018). Overall, these findings suggest that walking in green urban settings offers a certain level of physiological restoration (Valtchanov et al., 2010). However, we did not find that green elements impacted alertness and heart rates (H2a not confirmed). To decrease physiological arousal, time is needed. Hence, the possible calming effect of vegetation may have been masked by the random order design that was applied to short trial durations (<30 s).

Gaze in the urban space is rarely directed straight a head (von Stülpnagel, 2020), especially in the absence of plantations. In more clouted environments as it is the case in urban settings, gaze orientation is directed towards the ground in order to detect possible obstacles (Van Cauwenberg et al., 2016). Even when contrasting different types of urban environments, we revealed an effect of vegetation. Indeed, gaze was directed less frequently towards the ground in urban vegetation than in urban concrete trials (H5a confirmed). This change in strategy was possibly motivated by the intention to widen the angle of view, by opening the torso and raising the head. This change in posture would offer individuals the means to observe more clearly the implemented trees and green surroundings.

Contrary to our predictions fixation points were more numerous and longer in urban vegetation than in urban concrete settings (H6a not confirmed). In nature green, gaze is free and offers walking experiences that are characterized by fewer gaze fixations than in urban environments (Valtchanov & Ellard, 2015). Gaze fixation durations are also longer to offer time for the viewer to focus attention and experience fascination. In our VR experiment, care was taken to offer realistic green elements. The design of the trees was modelled to resemble as best possible the different shades of natural green observed in Northern France in the spring. Using a simple Lickert scale, participants reported being fascinated by the design green elements, which probably contributed in increasing the number of fixations. Hence, journey fixations similar to those observed in natural settings were revealed here in VR offering time to the viewers for fascination and curiosity. Overall, our vegetation VR environments offered both the physiological affective component and the fascination aspect of the restorative benefits of nature, which are key features for clinical applications (Browning et al., 2020; Calogiuri et al., 2021).

### 4.3 The Impact of Color-Designs in VR Environments

The third objective of our study was to assess the impact of colorful designs and to assess whether color-designs are sufficient to offer the restorative effects of vegetation. Hence, we measured walking speed, which in previous research was reported to be lower in natural environments implemented with green and blue design elements (Meier et al., 2012; Mentzel et al., 2019). In our VR study, participants were invited to walk around the campus grounds following a painted line that could be white, colored or augmented with patches of color-designs. Results did not reveal effects of color-designs on walking speed (H3b not confirmed). Interest and arousal were however triggered with colors: perceived pleasantness was greater with color-designs than without (H1b confirmed). Furthermore, mean heart rates were greater with color-designs in both types of urban environments indicating that color-designs increased physiological arousal (H2b not confirmed). Hence, color-designs impact significantly both the valence and the arousal component of the affective states. Nevertheless, we had predicted the opposite effect of color-designs on arousal. It is the case that our color patches were multi colored, i.e., contained a mix of red, green and blue. Hence, our results confirm those reported in an ecological situation for which red colors were reported to trigger significant increases in perceived and physiological arousal when compared to green colors (Kutchma, 2014). The use of colorful design techniques could be used to encourage spontaneous movement and motivate fun physical activity. To promote calm and wellness, future studies should test the impact of design elements using green shades of color only.

Nature walks free gaze (Martı´nez-Soto et al., 2019). Hence, we predicted that color-designs could do the same. However, individuals looked more frequently towards the ground with design-colors than without, especially in the vegetation urban environments (H5b not verified). They also revealed greater numbers of fixation points. In other words, with floor markings, participants looked down and more frequently at their feet. Color patches attracted attention and may be able to offer a restorative effect by focusing attention outwards, away from the everyday inner worries that bugger the mind. Future studies could confirm such hypothesis by including an estimation of the power of color-designs to help individuals lose track of time (Davydenko & Peetz, 2017). In the city, gaze is captured by the cluttered visual environment and engages attention; such noisy visual surroundings is a plausible explanation of why cities are perceived as mentally tiring. A freeing gaze is a source of mental relaxation. The data reported here confirm the restorative effect of virtual green environments with lower proportions of gaze fixation in the green environments (Nature and Nature Color Lines). On the other hand, the colorful designs limited the freezing of gaze.

Colors are identified faster than other features like shape and size (MacKay & Ahmetzanov, 2005). Therefore, urban planners could use our VR method and use scientifically based visual interventions to encourage citizens to pay attention to ground surfaces, e.g., when a road is under construction or in threat of flooding. The use of color-design principles could be also powerful to guide popup interventions that would control gaze travel through the city and the woods. Used to catch the attention, designs that stick out and automatically capture the curiosity of pedestrians could be created specifically to nudge more active life styles. In all these case studies, VR would be a well suited and innovating tool to guide design choices.

## 5 LIMITATIONS

Although our work reports significant results, several limiting factors remain. The number of blinks per minute was used as a measure of pedestrian cognitive process. Previous research has shown that blink rate is around, and a lower cognitive load produces a higher blink rate (Ledger, 2013). We report blink rates of similar frequency than that reported in natural settings e.g., (Barbato et al., 2007). However, there was an absence of effects of both environment and condition. Such measure may not be sensitive enough in VR and confirms similar levels of cognitive load across conditions.

Secondly, we adopted an experimental design that recorded short trials to avoid fatigue and nausea. Hence, the familiarisation phase was short, which may be the cause of certain order effects reported in the results section. More importantly, parameters such as cognitive performance and electrodermal activity could not be measured. Indirect measures were proposed with, for example, the measure of blink rates and heart rate variability (HRV) to estimate cognitive load and physiological stress, respectively. However, even if a tendency was observed for the later, we report an absence of significant effects; hence, we can not here report data to confirm the beneficial effects of green and colorful elements on well being. Further developments in VR technology will quickly offer the means to implement longer trials, which will be key to further study the influence of color interventions in the urban environment on cognitive stress.

Finally, this study used a limited number of designs and a unique urban setting. Hence, we can not report on the impact of, e.g., shape, size, brightness and achromatic patterns of design elements in the environment. Our aim here was to demonstrate the usefulness of VR technology in design choices. Future studies will be able now to further develop our code to consider more specifically what design principles can impact a pedestrian's walking experience to nudge the desire to be active.

## 6 CONCLUSION

We have reported a pre-post method that demonstrated that trees and green patches of grass can offer beneficial levels of fascination and low stress levels by providing positive affective states. Color alone is not sufficient to offer the restorative effects of vegetation in urban cities, but color interventions in urban spaces can increase fascination, curiosity and physiological levels of arousal. We demonstrate that nature and color interventions do not have similar impacts on the users. Color-designs promote greater levels of arousal that can be used to engage individuals in soft mobility. Our results are important as they suggest the importance of prototyping and of the design-evaluation. Even if painting is a low-cost technique, the financial cost of street art and color design implementation is none negligible. Virtual reality applications may be used to predict behavioral changes and hence, may offer guidelines to orient decisions on what and how to implement changes in the real world.

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://doi.org/10.5281/zenodo.5658185.

## ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

AB and YD-T were responsible for the conceptualization and management of this study. AB and FV devised the methodology, conducted the investigation. FV contributed to the data and statistical analyses. AB wrote the original draft. FV contributed editing and visualization of data. YD-T contributed resources, review and editing.

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REVIEW
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# Embodied Virtual Patients as a Simulation-Based Framework for Training Clinician-Patient Communication Skills: An Overview of Their Use in Psychiatric and Geriatric Care

*Laurence Chaby[1,2]*, Amine Benamara[3], Maribel Pino[4,5], Elise Prigent[3], Brian Ravenet[3], Jean-Claude Martin[3], Hélène Vanderstichel[6], Raquel Becerril-Ortega[6], Anne-Sophie Rigaud[4,5] and Mohamed Chetouani[2]*

*[1]Université Paris Cité, UFR de Psychologie, Boulogne-Billancourt, France, [2]Sorbonne Université, CNRS, Institut des Systèmes Intelligents et de Robotique, ISIR, Paris, France, [3]Université Paris-Saclay, CNRS, Laboratoire interdisciplinaire des sciences du numérique, Orsay, France, [4]Université Paris Cité, Maladie d'Alzheimer, Paris, France, [5]Service gériatrie 1&2, Centre Mémoire de Ressources et Recherches Ile de France-Broca, AP-HP, Hôpital Broca, Paris, France, [6]Univ. Lille, ULR 4354 - CIREL - Centre Interuniversitaire de Recherche en Éducation de Lille, Lille, France*

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*Ali Oker,*
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*Jordi Vallverdu,*
*Universitat Autònoma de Barcelona, Spain*

****Correspondence:***
*Laurence Chaby*
*laurence.chaby@u-paris.fr*

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Clinician-patient communication is essential to successful care and treatment. However, health training programs do not provide sufficient clinical exposure to practice communication skills that are pivotal when interacting with patients exhibiting mental health or age-related disorders. Recently, virtual reality has been used to develop simulation and training tools, in particular through embodied virtual patients (VP) offering the opportunity to engage in face-to-face human-like interactions. In this article, we overview recent developments in the literature on the use of VP-simulation tools for training communicative skills in psychiatry and geriatrics, fields in which patients have challenging social communication difficulties. We begin by highlighting the importance of verbal and non-verbal communication, arguing that clinical interactions are an interpersonal process where the patient's and the clinician's behavior mutually shape each other and are central to the therapeutic alliance. We also highlight the different simulation tools available to train healthcare professionals to interact with patients. Then, after clarifying what communication with a VP is about, we propose an overview of the most significant VP applications to highlight: 1) in what context and for what purpose VP simulation tools are used in psychiatry (e.g. depression, suicide risk, PTSD) and geriatrics (e.g., care needs, dementia), 2) how VP are conceptualized, 3) how trainee behaviors are assessed. We complete this overview with the presentation of *VirtuAlz*, our tool designed to train health care professionals in the social skills required to interact with patients with dementia. Finally, we propose recommendations, best practices and uses for the design, conduct and evaluation of VP training sessions.

**Keywords: virtual and e-learning, virtual patient, geriatrics and gerontology, psychiatry, clinician-patient communication/relationship, non-verbal communication (NVC), embodied conversational agent (ECA), human-agent interaction (HAI)**

# INTRODUCTION

*"Medicine is an art whose magic and creative ability have long been recognized as residing in the interpersonal aspects of patient-physician relationship"* (Hall et al., 1981). Creating and maintaining an effective and trustworthy clinician-patient relationship is fundamental for providing high-quality care (Ha and Longnecker, 2010). More specifically, the professional practice of health providers includes important verbal and non-verbal communication skills, especially during face-to-face interaction in order to promote therapeutic alliance (Zolnierek and DiMatteo, 2009) and patient's satisfaction (Brown et al., 1999). Communication skills refer to the ability to convey information to another person effectively (Beaulieu et al., 2011). Thus, they refer not only to what is said but how it is said through non-verbal behavior, including tone of voice (prosody), active listening, empathy, gestures, body language, and facial expressions used when interacting with another person. Training in communication techniques for health professionals has become a major issue in health education. However, health training programs do not provide sufficient clinical exposure and supervision to acquire these essential skills (Brown et al., 1999). Recently, virtual reality (VR) has been used to develop simulation and training tools (Pottle, 2019), notably through embodied virtual agents (Lee et al., 2020), in order to respect the fundamental ethical principle of *"never the first time on a patient"* (Granry and Moll, 2012).

## Clinician-Patient Communication: Why and How?

Interactions between a clinician and a patient can vary greatly depending on the clinical context (anesthesia, surgery, nursing, neurology or psychiatry), age (pediatrics, geriatrics) or state of the patient (comprehension capacity, cognitive or psychological profile). In any clinical context, successful interactions are generally associated with better adherence to care or treatment (Catty, 2004), medical outcome (Ruberton et al., 2016), enhanced mutual trust (Khullar, 2019) and patient satisfaction (Williams et al., 1998). Conversely, poorer or negative interactions can lead to medical non-adherence (Piette et al., 2005), patient distrust (Hawley, 2015) or clinician burnout (Chang et al., 2018). Successful interactions are driven by verbal and non-verbal communication. Verbal communication serves to evoke a reality and includes the content of what is said (intonation, choice of words) or even active listening (Kee et al., 2018). Non-verbal communication, whether intentional or unintentional, enables information to be shared without using speech, and includes social signals such as facial expressions, eye contact, head movements, posture, touch, interpersonal distance or tone of voice (for a review see Hall et al., 2019). While verbal communication is undoubtedly important during medical consultations and care (Conigliaro, 2007), non-verbal communication also plays a crucial role as it can reinforce or contradict verbal communication and thereby be instrumental to patient satisfaction or treatment outcome (Ambady et al., 2002; Lorié et al., 2017).

Clinicians should be concerned about their own non-verbal behavior as it influences the success of the consultation (Strasser et al., 2005; Roter et al., 2006). Specifically, maintaining eye contact, smiling, maintaining an adequate distance or direct body orientation with legs and arms uncrossed, and arm symmetry is generally associated with greater patient satisfaction (Beck et al., 2002). In addition, communicating positive messages and signs of empathy to patients can lead to better therapy outcomes, even in patients with serious illnesses (Hojat et al., 2011; Howick et al., 2018). Such elements may also lead the patient to judge the clinician as being warm and competent (Howe et al., 2019). Clinicians should also be skilled at identifying patients' non-verbal behaviors, typically for diagnostic purposes, such as using facial or vocal cues to assess patient pain (Ruben et al., 2018) or mood changes in severe depression (Ellgring and Scherer, 1996; Douglas and Porter, 2010).

In the psychiatric or geriatric field, clinicians are expected to interpret specific non-verbal cues associated with patients' psychological and behavioral symptoms, including signs such as emotional blunting, anxiety, apathy or aggression (Lehman et al., 2004; Templier et al., 2015). These behavioral symptoms are known to be difficult for clinicians to address and may even lead them to experience stress and burnout (O'Connor et al., 2018; Isik et al., 2019).

The dynamic non-verbal interaction between clinician and patient, which refers to the way in which the behavior of each interlocutor shapes and influences that of the other, is a crucial element in clinical practice (for a review, see Henry et al., 2012). Most research on non-verbal behavior in clinician-patient communication has been observational, focusing on examining associations with the collaborative relationship between clinician and patient (i.e., the therapeutic alliance) or with treatment outcomes. For instance, during a routine consultation, Lavelle et al. (2015) reported that when the patient displays pro-social behaviors that initiate or maintain interaction (i.e., direct gaze, smiling, nodding, using hand gestures), this in turn leads the clinician to display similar pro-social behavior and results in a better therapeutic relationship. Other studies that analyzed the vocal behavior of clinician-patient dyads from audio recordings have shown that synchronization between clinician and patient in prosody (Imel et al., 2014) or silence (Tomicic et al., 2017) plays a key role in clinical interaction and is associated with a better therapeutic alliance. This behavioral synchrony has also been evidenced with physiological measures, such as levels of electrodermal activity (Marci et al., 2007; Bar-Kalifa et al., 2019) or heart rate (Kodama et al., 2018), suggesting that in clinician-patient dyads, both partners tend to experience concomitant emotional activation. Interestingly, other methods have focused on assessing the relationship between clinicians and patients through automated objective videotape analysis algorithms. Ramseyer and Tschacher (2011, 2014), for instance, reported that in face-to-face psychotherapy, greater coordination of the patient's and clinician's body and head movements is associated with more positive therapeutic relationships and greater patient self-efficacy. Hence, the objective characterization of the dynamics of the clinician's

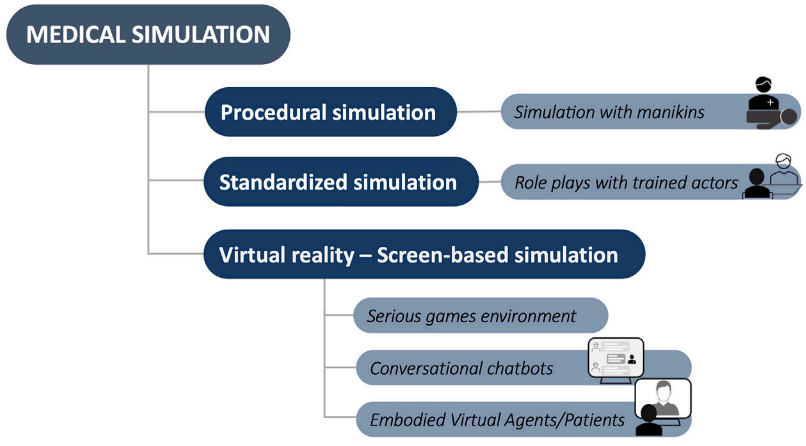


**FIGURE 1 |** Simple classification of healthcare simulations. *Procedural simulation* is based on manikins that represent a full or partial human body; *Standardized simulation* is based on role-playing with patients played by actors in real clinical situations or through videos; *Virtual reality* simulation is based on computer technology to create interactive virtual worlds that the user can interact with (e.g., serious games, conversational chatbots or Embodied Virtual Agents.).

and patient's movements provides a quantification of the non-verbal synchrony (see Delaherche et al., 2012). More recently, a two-person brain imaging interactive study (fMRI hyperscanning) has identified a potential brain-behavioral mechanism supporting the clinician-patient relationship. It showed that the mirroring of facial expression and brain-to-brain concordance in the temporo-parietal junction (TPJ) was significantly associated with patient analgesia and therapeutic alliance (Ellingsen et al., 2020).

Effective communication skills are an essential component of successful interactions between clinicians and patients. However, patients may exhibit inappropriate behaviors such as aggression, isolating themselves or refusing to respond to those who try to communicate with them, or refusing to take medication or follow treatments. It therefore appears crucial to train clinicians on how to communicate with patients from a person-centered care perspective (Del Piccolo and Goss, 2012), which means respecting and responding to the needs and values of each patient (Lewin et al., 2001; Hardman and Howick, 2019). Yet, this raises the question of whether non-verbal communication skills can be taught. In fact, it is not so much about developing specific non-verbal communication skills but more about using non-verbal communication to develop engagement, reciprocity, and synchronization in order to create a genuine therapeutic alliance that bonds the clinician and the patient (Shattell et al., 2007; McGilton et al., 2009). In any case, training and evaluating non-verbal communication and their links with clinical outcomes is challenging, often intrusive (e.g., real-time observation) or can require extensive resources (e.g., interactions involving actors representing standardized patients; Henry et al. (2012).

## Medical Simulation in Healthcare Education

Medical simulation, which is increasingly being promoted by health authorities in many countries (Forbes and Kennedy, 2009; Granry and Moll, 2012; Alinier and Platt, 2014), refers to the use of standardized devices or virtual reality tools to emulate a clinical context to teach or train a health professional in clinical, therapeutic or diagnostic procedures (Ker and Bradley, 2010). The purpose of medical simulation is to reproduce real world clinical scenarios in a standardized, safe and reproducible context, which facilitates the immersion of trainees during their initial or continuing education (Gaba, 2004). While medical simulation cannot substitute for clinical experience, it offers the opportunity to receive feedback and gain confidence without going through the real clinical event or remaining 'far away from the patient' the first few times of practice (Okuda et al., 2009; Wolf et al., 2011).

In the field of healthcare, a variety of simulation techniques (see **Figure 1**) are thus suitable for both novice or expert trainees for psychomotor, cognitive, affective or communicative learning tasks (Munshi et al., 2015). 'Procedural simulation' conducted using realistic part- or whole-body manikins is the most traditional (Lapkin et al., 2010) and is mostly used to facilitate the learning of psychomotor skills such as surgery gestures or nursing care (see Rivière et al., 2018). 'Standardized simulation' is structured in the form of role-play with well-trained actors to simulate clinical scenarios or to portray a patient with a specific health concern (i.e., human standardized patient) providing in-depth experience of clinical reasoning, decision-making or communication techniques in various situations, including crisis intervention (Brender et al., 2005; Keltner et al., 2011). However, the use of standardised simulation is limited due to the high costs of recruiting and training patient actors, especially when actors need to play an adolescent, an elderly person or a person with mental health issues (Keiser and Turkelson, 2017). In addition, this type of simulation can also lead users to feel uncomfortable or apprehensive about acting in front of their peers (Albright et al., 2016). Finally, 'virtual reality' (VR), which has developed extensively over the last 2 decades in the field of healthcare, refers to a computer-screen-based simulation that offers a multisensory and immersive interactive experience in a safe environment (Mantovani et al., 2003; Rizzo et al., 2017; Riva and Serino, 2020). These techniques can be used to implement applications such as 'serious games' in which the trainee is confronted with virtual situations drawn from real-life events, allowing them to develop clinical reflexes (e.g., from the discovery of patient files to the administration of medication) (Wang et al., 2016) and that can incorporate the notion of feedback or scoring (Stuckless et al., 2014). Such tools may take the form of virtual world platforms such as Second Life® (see Irwin and Coutts, 2015) or The Sims$^{TM}$ (Arts, 2009), and allow for the creation of virtual hospital units (Aebersold et al., 2012) and interactions with virtual patients. Virtual simulation can also be implemented in the form of conversational agents such as 'chatbots' that can interact with users by simulating a human conversation through text or voice *via* smartphones or computers, and are able to interpret the user's responses. Chatbots have shown their potential to promote clinician-patient communication (Friedman et al., 1977; Madhu et al., 2017; Jagtap et al., 2021).

A more recent breakthrough in the field of healthcare is the use of Embodied Conversational Agents or ECAs. One approach, especially in the field of mental health (see Provoost et al., 2017) has been to use ECAs for diagnostic or remediation purposes, either as partners of social interaction (Georgescu et al., 2014; Tanaka et al., 2017b; Grossard et al., 2020), virtual coaches motivating the user (Torres et al., 2018; Ali et al., 2021), or even for virtual clinical interviews with real patients suffering from depression, post-traumatic stress disorder or dementia (Stratou et al., 2015; Philip et al., 2017; Mirheidari et al., 2019). In addition, ECAs have also come to be used as 'virtual patients' (VPs), i.e., representing a patient alone or in a virtual environment and offering the trainee (clinician or student) the possibility to engage in a human-like face-to-face interaction (see Combs and Combs, 2019). As such, medical educational strategies are increasingly shifting toward the use of VP simulations, as they are more scalable and reproducible, being available at all times and places, while providing learning outcomes comparable to standardized clinical learning environments (Consorti et al., 2012; Quail et al., 2016), including improved skills when interacting with real patients (Cook and Triola, 2009). It has also been shown that people show empathetic responses (Deladisma et al., 2007) and tend to show more willingness to disclose information when interacting with virtual compared to real humans, possibly because of this "soothing" effect since "after all, it is just a computer" (Lucas et al., 2014).

## Aim of the Overview

The benefit of VPs for the training of so-called soft or non-technical skills, including communication or decision-making, has been surveyed elsewhere. One of the first reviews to show a benefit of VPs was on clinical reasoning rather than on communication itself (Cook et al., 2010). Another systematic review, that did not cover communication skills, reported that simulation using VPs can enhance clinician empathy among healthcare students (Bearman et al., 2015). An integrative review in the field of nursing demonstrated the value of VPs for developing decision-making, communication, or teamwork skills (Peddle et al., 2016). More recently, a systematic review in the context of pharmacist-patient interactions also showed the benefit of VPs in developing communication or counseling skills (Richardson et al., 2020). In addition, Lee et al. (2020) conducted a systematic review focusing on the design and evaluation characteristics allowing for effective medical communication skills education based on VP simulation. None of these reviews, however, covered studies on training communicative skills with embodied VPs displaying psychiatric or geriatric disorders.

It should be pointed out, however, that communicating with patients with psychiatric disorders (e.g., depression, schizophrenia, personality disorders) or age-related and degenerative disorders (e.g., dementia) is considered as very challenging because of the behavioral, thinking or language disturbances that occur with the illness (Hartley et al., 2020). However, this dimension is not sufficiently taken into account in the training of clinicians, in particular non-verbal communication to which these patients are very sensitive, thanks to their partially preserved capacity to integrate multimodal social signals (Maurage and Campanella, 2013; Giannitelli et al., 2015; Templier et al., 2015; Xavier et al., 2015).

The aim of the present article is to highlight the relevance of technology-assisted education through VPs, in addressing the specific challenges facing the training of clinician-patient communication in psychiatric and geriatric care education. We start by explaining what communicating with a VP is about, and by describing their role in training communication skills in psychiatry and geriatrics by presenting important studies in this field (see **Table 1**). Our intention is to provide a roadmap for those interested in learning more about the use of VP as a simulation framework for training clinician-patient communication skills, including their strengths and weaknesses, in psychiatric and geriatric care education. To that purpose, the overview is driven by highlighting several key features of VP simulation tools (see **Figure 2**) related to the VP itself (e.g., predominant competencies, underlying simulation model, tool evaluation) and the user (e.g., target competencies, underlying clinical situation, user evaluation).

# ROLE AND INTEREST OF EMBODIED VIRTUAL PATIENTS IN HEALTHCARE

## Communication With an Embodied Virtual Patient: What Is This About?

Virtual Reality-based technologies are increasingly used in the field of healthcare and scientific research for simulating cognitive and socio-emotional skills (Riva and Serino, 2020) or studying human social interaction (Pan and Hamilton, 2018). Thus, it is now possible to interact and communicate with a virtual partner, such as embodied conversational agents (ECA) (Cassell et al., 2000; Loveys et al., 2020; Pavic et al., 2020), and thanks to the ability of ECAs to simulate and mimic human behavior, users tend to interact with them as with a real person (Gratch et al., 2013) and to assign them mental states (Callejas et al., 2014). In the context of healthcare simulation training, embodied VPs are typically computer-based programs using ECAs and simulating real patients and emulating a clinical encounter (see Cook and

**Table 1 |** Overview of annotated attributes in our selected list of articles presented on **Section 2**. The annotation procedure captures the user and the VP characteristics in simulation tools for clinician-patient communication in the field of psychiatry and geriatrics.

| **Article** | **User** | | | | | | | | | | **Virtual Patient** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Predominant Competency** | | | **Underlying Situation** | | **User Evaluation** | | | | | **Predominant Competency** | | | **Underlying Simulation Model** | | | **Tool Evaluation** | | | | **Patient Type** |
| | **Communication Skills** | **Empathy** | **Teamwork** | **Clinical Encounter** | **Conversation** | **Questionnaires** | **Videos Annotation** | **Speech Annotation** | **Automatic Behavior Analysis** | **Debriefing/Feedback** | **Verbal Behaviors** | **Non-verbal Behaviors** | **Monitoring User Behaviors** | **Text-Based Interface** | **Fully Autonomous** | **Wizard-Of-Oz** | **Acceptability** | **Usability/Credibility** | **Training Effectiveness** | **Feeling of Presence** | **Pathology** |
| Carpenter et al. (2012) | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | Depressive child |
| O'Brien et al. (2019) | ● | ● | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● | ● | ○ | ● | ● | ● | ○ | Young adult with suicidal thoughts |
| Shah et al. (2012) | ● | ● | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | Major depression |
| Cordar et al. (2014) | ● | ● | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | Major depression |
| Parsons et al. (2008) | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ● | ● | ○ | PTSD |
| Kenny et al. (2009a); Kenny et al. (2009b) | ● | ○ | ○ | ● | ○ | ○ | ◐ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ● | ● | ○ | PTSD |
| Pantziaras et al. (2014); Pantziaras et al. (2015) | ● | ◐ | ○ | ● | ● | ● | ○ | ◐ | ◐ | ● | ○ | ● | ◐ | ● | ● | ○ | ○ | ● | ● | ○ | PTSD refugee |
| Dupuy et al. (2020) | ● | ● | ○ | ● | ○ | ● | ● | ● | ● | ● | ○ | ● | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | Depressive symptoms |
| Ochs et al. (2017, 2019) | ● | ● | ○ | ○ | ● | ● | ● | ○ | ● | ○ | ● | ● | ● | ○ | ◐ | ◐ | ○ | ● | ○ | ● | Patient receiving bad news |
| O'Rourke et al. (2020) | ● | ○ | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | Patient receiving bad news |
| Orton et al. (2008) | ◐ | ○ | ◐ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ◐ | ○ | ○ | ● | ● | ○ | ○ | ● | ● | ○ | Elderly with care needs; Dementia |
| Liaw et al. (2019) | ● | ○ | ● | ● | ○ | ● | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ● | ● | ● | Elderly with care needs |
| Robinson et al. (2020) | ● | ○ | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | Dementia |
| Szilas et al. (2019) | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ◐ | ● | ○ | ○ | ○ | ○ | ○ | Alzheimer Disease |

●*: Yes;* ○*: No;* ◐*: In-between.*

Triola, 2009; Su and Chang, 2021). The challenge is then to provide enough realism and reliability to make the learner's experience sufficiently relevant and useful (see Talbot and Rizzo, 2019). One approach is to offer case-based training whereby the interaction with the VP unfolds as a function of the trainee's responses (see Staccini and Fournier, 2019; Staccini, 2021). VPs can be fully autonomous and engage in brief interactions with the user, under no human control, or can be controlled by a human operator, through a Wizard-of-Oz (WoZ) procedure, which controls the verbal or non-verbal responses of the virtual patient during the interaction (Fraser and Gilbert, 1991; Riek, 2012). Whether automated or human-controlled, computer systems are generally equipped to record the user's non-verbal behaviors (e.g., voice, gestures, body movements, gaze, or facial expressions) and use them to modulate the evolution of the interaction, giving a high degree of realism and social presence (Fox et al., 2015). In the context of communication training, the overall value of using VPs in the field of healthcare is that they offer the opportunity to practice communicating with patients in a stress-free context (Elzubeir et al., 2010) where mistakes or bad decisions are inconsequential (e.g., breaking bad news, Carrard et al., 2020). This type of virtual environment also gives the trainee the opportunity of self-observation, allowing for the identification of the most effective communication practices and thereby increasing self-confidence (Baumann-Birkbeck et al., 2017). Such a tool may finally be supplemented by an evaluation or coding of the trainee's verbal or non-verbal behaviors, via external judges or by computer-based automatic analyses.

## VP-Simulation for Clinician-Patient Communication in Psychiatry

Psychiatry is a medical specialty that focuses on the diagnosis, treatment, and prevention of mental, emotional, and behavioral disorders. In recent years, the prevalence of disorders such as anxiety, depression, and stress has increased significantly (see Steel et al., 2014), and was magnified further during the COVID-19 crisis (Castelli et al., 2020; Salari et al., 2020). Other chronic and severe mental disorders, such as schizophrenia, involve social communication difficulties (Burns, 2006) that can be difficult for the clinician to address (McCabe et al., 2013). These difficulties, associated with the stigmatization of patients (Hinshaw and Stier, 2008), as well as stress, burnout, or job dissatisfaction of mental health professionals (Rössler, 2012), has motivated paradigm shifts in medical communication and education approaches. It has been shown, for instance, that ineffective psychiatrist-patient communication is associated with poorer patient outcomes and experiences (Schneider et al., 2004). However, although there are several guides on how to communicate with psychiatric patients (Priebe et al., 2011), studies of non-verbal behaviors in psychiatry are limited (Cruz et al., 2011) and efforts have to be made to improve clinician-patient communication in this field. In this context, training practices based on clinical simulation, including VP-simulation, have the potential to provide health care professionals with safe and controlled tools that can help them develop the necessary skills to care for or communicate with patients experiencing mental disorders (McNaughton et al., 2008; Piot et al., 2020).

One area where VP simulation has proven successful is in training clinicians to interact with people suffering from severe depression or at risk for suicide, as they allow for repetition in practice with challenging scenarios that clinicians may face. One of the first use cases of VPs in the field of psychiatry was designed as a web-based platform to train clinicians to assess suicide risk in youth (Carpenter et al., 2012). The Suicidal Avatars for Mental Health Training (SAMHT) platform allows the user to face a VP who can move, speak and is embodied as a child suffering from depressive symptoms. The user converses with the VP by selecting questions related to suicide risk from a predetermined text-based list, which are repeated by a synthesized voice (as if the user was asking the question) and allows the VP to respond through an intelligent decision tree. One of the major limitations of this study, which appears to be a proof of concept, is that it did not consider the educational value of the tool nor the trainees' behaviors. More recently, another work (O'Brien et al., 2019) tested the acceptability and benefit of VP simulation, using The PeopleSim® technology, to train mental health practitioners to interact effectively with individuals at risk for suicide. The VP embodies a fictive 20-year-old female patient who states that she has thought about committing suicide. In the scenario, the patient comes to the clinic to be evaluated on her ability to return to work. The trainee's goal is to encourage the patient to share details of her thoughts to assess the immediate risk of suicide, while empathizing with the patient's thoughts. The proposed simulation consists of a unidirectional interaction with the VP–*via* a text-based interface incorporating pre-recorded videos of the patient–where the trainee can select from a list the question to ask the patient who can answer via a chat window. Based on their choices, an on-screen virtual instructor also provides text-based advice or feedback to help trainees improve their skills. After the conversation, the 20 participants who took part in this pilot study found the training experience to be satisfactory (feasibility and acceptability), especially in terms of training communication skills. Finally, the trainees' knowledge (assessed using pre-post training questionnaires) showed a significant improvement. A limitation of this work is that with the pre-recorded videos of the VP, the interaction lacks naturalness, and the verbal and non-verbal behavior of the trainee is not taken into account.

Using The Sims video game, other studies have focused on the use of VPs to enhance the empathy and interpersonal communication skills of medical students during interactions with a 21-year-old virtual patient (Ms. Cynthia Young) suffering from major depressive episodes (Shah et al., 2012; Cordar et al., 2014). The interaction between the trainee and the VP was bidirectional (i.e., each can ask the other participant questions according to a predefined script) and relied on a text-based interface incorporating images of the patient (Shah et al., 2012) or 90-s cutscenes depicting short moments in the VP's life to provide a backstory (Cordar et al., 2014). These studies focused mainly on the evaluation of the educational tool by the students via questionnaires. Trainees expressed overall satisfaction of the interaction with the VP, found the tool easy

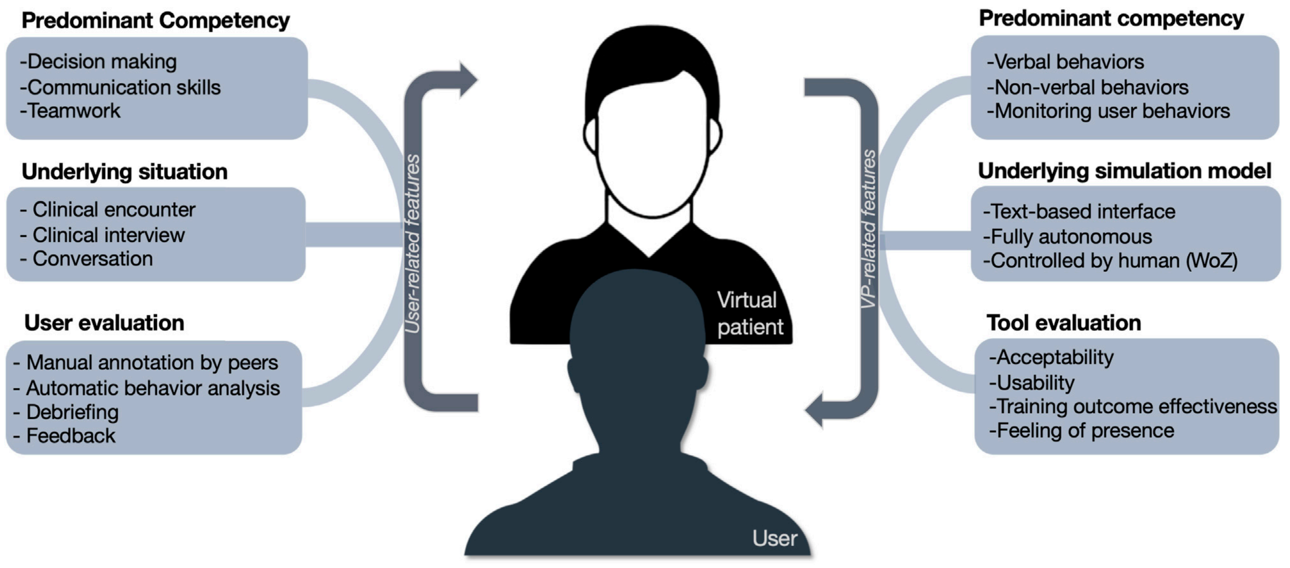


**FIGURE 2 |** Key features of healthcare simulation tools using embodied virtual patients (VPs), applicable to the user and the VP. On the left, those concerning the user (e.g., clinician, student), including the *predominant competencies* targeted for training, the type of *underlying situation* simulated, as well as the *user evaluation*; On the right, those concerning the embodied virtual patient, including the *predominant competencies* of the VP, the *underlying simulation model*, and the *tool evaluation* by the user. *WoZ: Wizard-of-Oz*.

to use, and considered that it could represent a good educational tool. The empathy of 35 trainees was evaluated (Cordar et al., 2014) from text-based transcripts only (with or without VP backstory) and users' verbal or non-verbal behaviors were not considered. Results suggested that VPs with a backstory, showing how the patient may be affected by their illness, are an effective training tool for interpersonal communication skills, such as empathy. A limitation of these studies is that, in the limited environment of 3D virtual world games, VPs are not able to converse in a realistic manner, nor respond to dialogues with human-like non-verbal behaviors or emotions.

A further area where VP simulation has proven effective is in training to interact with people with post-traumatic stress disorder (PTSD). PTSD is a psychiatric disorder related to trauma caused by exposure to a traumatic or stressful event (e.g., war, natural disasters, terrorist attacks, assaults) usually resulting in persistent feelings of anxiety and psychological distress, and potentially leading to altered social-emotional behaviors or depression (Zoellner et al., 2014). Several studies in this area (e.g., Parsons et al., 2008; Kenny et al., 2009a,b) have focused on improving the interviewing or communication skills of mental health students by having them interacting with a VP embodied in Justina[1], a female adolescent suffering from PTSD following an assault. Interactions were designed as a 15-min clinical interview in which 15 novices in mental health (Parsons et al., 2008; Kenny et al., 2009a) or 15 novice and nine expert mental health clinicians (Kenny et al., 2009b) were asked to assess a patient's initial diagnosis of PTSD. The VP, displayed on a computer screen, spoke in natural language with the user. Interestingly, the user's speech was recorded and transcribed in real-time so that it could be interpreted by a statistical question-answer system (i.e., based on a real clinical corpus) to generate the VP's verbal behavior. The transcription of the whole dialogue session was also recorded and annotated in terms of whether clinicians asked the appropriate questions needed to determine whether the patient reported symptoms that met the criteria for PTSD. Overall, results of these studies (see also Rizzo and Shilling, 2017) showed a good evaluation of the credibility of the tool by users, despite encountering some problems with voice recognition. In addition, novices asked the VP more questions about general matters whereas experts were better able to ask the specific questions needed to make a differential diagnosis. While this approach is promising, it focused on natural language, and the fact that non-verbal behaviors such as users' facial expressions were recorded but not yet exploited in the study somewhat limits its impact.

Another application of VPs concerns the training of health care professionals in the field of transcultural psychiatry and refers to clinicians' interactions with patients from diverse ethnic backgrounds. Pantziaras et al. (2014, 2015) developed a VP system called Refugee Trauma Simulation (RT-SIM) portraying a refugee (Mrs K) exhibiting severe symptoms of PTSD. The interaction, based on a predetermined question-answer scenario, was designed as a virtual psychiatric interview (up to 45 min) requiring 32 residents in psychiatry to provide a differential diagnosis and treatment program of a refugee with PTSD. The VP tool aimed at providing knowledge and training on identifying PTSD symptoms, clinical management, and communication skills. The VP displayed on a computer screen was depicted using pre-recorded video clips and used prerecorded sentences that were played according to the

[1]https://www.youtube.com/watch?v=jy1NKDz47aQ&t=14.

questions chosen by trainees on a list. An interesting element of this tool was the inclusion of an automated feedback module covering the VP's perspective on the consultation, the clinical aspects of PTSD diagnosis/management, and the trainee's communication skills. This feedback was given in the form of a video presentation of the virtual patient (VP) speaking directly to the trainee (e.g., perceived level of empathy, relevance of questions asked to the problems encountered). Assessments included both tool evaluation (credibility, usability, and effectiveness) by the trainees and trainee evaluation (self-report of emotional reactions, questionnaire-based assessment of PTSD knowledge acquisition, and assessment of communication skills). Overall, the results showed that the tool was positively evaluated by the trainees in terms of ease of use and effectiveness. In addition, the training session had a significant impact on the improvement of knowledge (pre- and post-interaction). Of note, the follow-up evaluation, several weeks after the interaction, showed that the knowledge gain decreased over time, suggesting that a single training session with the VP does not seem to be sufficient to ensure long-term learning. A limitation of the study is that the article did not provide any details about how communication skills were automatically analyzed by the system and evaluated.

More recently, a study focused on improving the empathic communication skills of medical students during realistic psychiatric interviews with a middle-aged VP with affective disorders (Dupuy et al., 2020). Interestingly, the simulation was not exclusively text-based or speech-based as in previous studies, but also addressed the VP's non-verbal behavior as well as the trainees' non-verbal and empathic behavior. The interaction, based on a predetermined question-answer scenario, was designed as a 35-min psychiatric interview requiring 35 students (medical, psychiatric) to conduct interviews with a middle-aged VP with major depressive disorder and to extract semiology (i.e., clinical manifestations). The VP was displayed on a large human-sized screen and could interact with the user in natural language, allowing the user's speech to be interpreted via a speech recognition system. The strength of this study is that it emphasized not only the non-verbal behaviors of the VP (prosody, gestures, movements) but also those of the trainees (recording of facial expressions, with manual annotation of the videos and automatic analysis by an emotion recognition software). The tool was positively evaluated, in terms of usefulness, realism and credibility, during a debriefing (i.e., semi-structured interview) with the trainees. The results also suggest that the trainees maintained a neutral face during the interview, a finding interpreted by the authors as a form of empathy and the ability to maintain a certain emotional distance. Overall, this work highlights the added value of automatic facial expression recognition in psychiatry training.

A last interesting proposal consists in training health professionals to break bad news to patients, which requires fine skills in psychology, non-verbal behaviors, and empathy. Although this work is not strictly in the field of psychiatry, it seemed relevant to all those who wish to learn more about the use of VPs for training clinician-patient communication skills, as breaking bad news is a frequent and challenging task for clinicians in most clinical specialties (Fallowfield and Jenkins, 2004). In psychiatry, this may include conversations about the irreversible cognitive impairment of schizophrenia in a young adult (Cleary et al., 2009), in geriatrics, conversations about death issues (Lenherr et al., 2012). Hence, breaking bad news with empathy and being involved in the struggle that follows can make a significant difference. In one work (Ochs et al., 2017, 2019), the scenario required the physician to explain to a patient that a complication had occurred during her operation, requiring a second operation in a day. The stated objective was to train the physician to verify that their verbal and non-verbal communication had the right impact on the patient. The 22 participants in this study (7 expert physicians, 12 naive students) interacted in natural language with the VP that communicated through verbal (e.g., questions) and non-verbal (e.g., nods, smiles) behaviors depending on the trainee's behaviors. To overcome the limitations of voice-based tools controlled via speech-to-text modules only (e.g., misunderstandings, frustration due to transcription errors), the authors preferred a Wizard-of-Oz (WoZ) procedure, where a human operator observes the user and updates the VP response accordingly. The strength of this study is that it displayed the VP in different formats, including a computer screen and two previously unexplored immersive virtual reality systems: a Head-Mounted Display (HMD) and a 3D immersive room with wall projection (CAVE). The objective was to analyze the effect of the immersion format on the users' feeling of presence. The results of the study showed that the CAVE seems to improve the trainee's experience (feeling of presence, perception of the virtual patient) and the credibility of the tool compared to the HMD and the computer screen. The results also showed that the immersive room (CAVE) is particularly suitable for physicians (i.e., more engagement) compared to naive participants, suggesting the potential effect of the "familiar" context on the interactive experience. Finally, although this approach is promising, especially via the fully immersive approach, the fact that the non-verbal behaviors (gestures, movement, facial expressions) of the users were recorded via sensors (i.e., Kinect) but not yet exploited limits its potential somewhat. In another recent study on the same topic (O'Rourke et al., 2020), 60 medical students were asked to deliver bad news to the spouse of a patient experiencing a medical error. The interest of this study was to compare the interaction in terms of communication skills with an embodied VP or a standardized patient (SP) played by a paid actor. The VP, displayed on a large human-sized screen and controlled by a human operator in a WoZ-like procedure, communicated through verbal and non-verbal behavior (head movements, facial expressions, and gestures). The tool, which was rated by users in terms of credibility, was found to be less authentic with the VP compared to the SP. The novelty of this study was to assess communication performance (e.g., "Used appropriate eye contact") as well as trainees' pre-post interaction experience on an emotional level through subjective questionnaires and salivary cortisol concentration. Interestingly, the results of this study suggest that trainees' task performance and emotional reactions do not differ whether they interact with a SP or a VP.

## VP-Simulation for Clinician-Patient Communication in Geriatrics

Geriatrics is a medical specialty devoted to the health of elderly people by preventing and treating diseases and disabilities in the elderly. The population over the age of 65 is gradually increasing and, due to the general decline in their physical or cognitive health (Gill et al., 1996), has substantial needs in terms of health care (Hashimoto and Tabata, 2010). Elderly patients often present with complex pathologies that require extensive explanation by clinicians (see Ambady et al., 2002). In addition, they tend to be relatively passive in their interactions, probably for generational reasons or for apprehension of being perceived as disrespectful (Gorawara-Bhat et al., 2007). Furthermore, as the population ages, an increasing number of people are at risk of developing Alzheimer's disease or related dementia (Baumgart et al., 2015). Alzheimer's disease is characterized by a progressive decline in cognitive resources (e.g., memory, language, judgement, attention, etc.) and is associated with behavioral disorders (e.g., aggression, agitation, withdrawal or resistance to care) leading to interpersonal problems and contributing to the patient's loss of autonomy (Orange, 2001; Chaby and Narme, 2009). This leads to difficulties for the patient in expressing their needs or feelings, even though they may rely on non-verbal cues (prosody, facial expressions, gestures, etc.) over time (Alsawy et al., 2020), which implies several challenges for the clinician to communicate with them adequately (van Manen et al., 2020).

In geriatric practice, although the impact of clinicians' non-verbal behaviors on elderly patient outcomes is important as well (Ishikawa et al., 2006), methods to study clinicians' non-verbal behaviors are limited (Collins et al., 2011). A few studies have attempted to use behavioral methods through observation of video recordings to code the non-verbal Dimension in physician-Elderly Patient transactions (NDEPT), including the analysis of the physician's body language during the interaction such as posture, eye contact, facial expressions, and social touch (Gorawara-Bhat et al., 2007; Gorawara-Bhat and Cook, 2011; Stepanikova et al., 2012; Gorawara-Bhat et al., 2013). Interestingly, these studies found that eye contact was the most frequently used non-verbal behavior by clinicians when communicating with elderly patients.

In this context, it becomes crucial to increase the competence of the entire healthcare workforce to communicate and maintain relationships with this geriatric population. Unfortunately, this dimension is not sufficiently considered in the training of clinicians, although several studies have already shown the positive effects of sensitizing clinicians to the use of non-verbal (Magai et al., 2002; Machiels et al., 2017) and empathetic communication (Brown et al., 2020). While VP simulation in geriatrics education is still in its infancy, it has the potential to address several challenges, including reduced access to real patients and the need to provide safe settings in which trainees can learn or practice their clinical skills (Tan et al., 2010).

To find a way to bridge the gap and improve the relationship between health care professionals and older adults with dementia, a first attempt was to use immersive technologies that virtually expose the clinician to what an older adult with dementia experiences. For instance, the Virtual Dementia Tour® (Beville, 2002; Slater et al., 2019) or myShoes (Adefila et al., 2016) projects allow clinicians to "embody" an elderly patient in a nursing home, to experience the physical and sensory difficulties, as well as the memory loss, feelings, and frustrations associated with dementia-related problems. While not directly involving training through patient interaction, these virtual immersion techniques that allow clinicians to put themselves in the patient's shoes have shown to improve clinicians' empathy and non-verbal behaviors toward elderly patients in real clinical practice (see Campbell et al., 2021).

One of the first use cases for VPs in geriatrics was designed as a web-based platform to offer clinicians the opportunity of interacting with elderly patients in clinical care encounters (Orton and Mulhausen, 2008). The GeriaSims platform allows the user to interact with a VP embodied as an elderly person and displayed as an image or multimedia clip. The interaction can last one to 2 hours, including questions about history, physical examination, or choices about treatment. Several scenario topics (i.e., modules) are proposed, including cognitive and behavioral disorders in dementia, medication management, primary care, palliative care, or falls (e.g., Ruiz and Leipzig, 2008). Prior to the interaction, the trainee has access to the patient's backstory and the objectives of the encounter–which can be diagnostic or therapeutic–are indicated. The user converses with the VP by selecting questions from a predetermined text list. A virtual mentor is also available for assistance or guidance. At the end of the interaction, the tool was evaluated with questionnaires in terms of usability and effectiveness of learning. The authors report that the tool was rated by 287 trainees as easy to use and an effective way to achieve the targeted objective. An advantage of such a web-based tool is its accessibility at any time and place and thus the flexibility in planning training, which can be a drawback when using other VP simulation tools. One of the limitations, however, is that the VP is not able to converse in a realistic manner, nor respond to dialogues with non-verbal behaviors or human-like emotions. In addition, the trainee's verbal and non-verbal behaviors are not assessed.

Another particularly innovative aspect of VP simulation in geriatrics is the training of communication skills between members of geriatric care teams. These interprofessional approaches are known to improve care efficiency and patient health outcomes (Curran et al., 2007). In this regard, a recent study proposed an interprofessional virtual visit scenario with multiple healthcare professionals at the bedside of Mr. Jin, a 80-year-old man with pain and fever after surgery (Liaw et al., 2019). To provide a backstory, the patient's medical file is displayed on the screen before the interaction begins. Here, the various clinicians (physician, nurse, physical therapist, social worker, etc.) are integrated into the virtual environment via an avatar representing them and displayed on the screen and at the same time as the VP. The VP can communicate through verbal (synthesized voice) and non-verbal behavior (e.g., facial expressions, body movements, breathing noise, moaning) in response to the behavior of the clinicians, who can also communicate with each other. The tool was positively evaluated by the 29 trainees participating in the study in terms of usability and effectiveness, with a moderate evaluation of the feeling of presence. The interprofessional attitude of the trainees was also assessed by judges using a questionnaire. Overall, the results of this study show the feasibility of using a 3D environment simulation including a VP to foster social interactions and collaborative practices between multiple healthcare professionals to facilitate the sharing of information about the elderly patient. Note, however, that the non-verbal behavior of the participants was not recorded and or analyzed. Interestingly, this work was complemented by a study on the transferability –5 months after training–of virtual simulation learning to clinical practice (Liaw et al., 2020). Although the assessment of transferability to clinical practice was based on students' subjective perceptions via focus groups, the results indicated transferability effects through clinical practice and how working together with different healthcare professions could ensure a more holistic care of a patient.

Interestingly, a study by Robinson et al. (2020) focused specifically on training communication skills of 82 speech pathology students in realistic conversations with an elderly VP with behavioral symptoms of dementia and resident of a nursing home (for a full description of the tool, see Quail et al., 2016). The 15-min interaction was based on a predetermined scenario of verbal (e.g., comprehension difficulties, word search, confusion) and non-verbal (e.g., crying, shrugging, chuckling) responses that were representative of dementia. Trainees were instructed to have a conversation with the VP to identify any problems he might be experiencing. Following this, a 15-min feedback with a clinical educator was offered to the trainees, aimed at encouraging the trainee to engage in self-reflection, followed by a second 15-min interaction with the elderly patient. The VP was displayed on a large human-sized screen and could interact with the user in natural language, with the user's speech interpreted via a WoZ operator. The strength of this study is that it emphasized, for each clinical encounter, on the analysis of the trainee's verbal and non-verbal behavior based on speech transcription (e.g., "demonstrates awareness of how his/her responses are affecting the communication partner") and video annotation (e.g., "maintains appropriate eye contact"). This was coupled with a self-rating by the trainees of their communication skills. Findings revealed an improvement in students' communication skills in the second interaction, confirmed by the improved self-ratings. However, it is not possible here to distinguish the benefit of the simulation on the verbal vs non-verbal level. Although not directly focused on clinician-patient communication training, another related study deserves to be mentioned (Szilas et al., 2019) as it reports the preliminary implementation of an embodied VP simulation tool to support interactions between family caregivers of patients with Alzheimer's disease and the patient himself (i.e., a 65-year-old apathetic woman suffering from an early-stage Alzheimer Disease).

## VirtuAlz–A VP Tool for Training Clinician to Communicate With People With Alzheimer's Disease

As mentioned above, the development of simulation tools for training clinicians to communicate with people with dementia is still very limited. Here, we present a virtual VP tool called *VirtuAlz* that was designed for geriatric health professionals to sensitize them to the basic communication skills needed to interact with elderly patients with Alzheimer's disease. The tool, including the behavior of the Alzheimer's VP, is based on real clinical cases (e.g., medication administration, patient's wandering) derived from a field observation conducted in a geriatric service and an analysis of communication training needs in this field (Becerril-Ortega et al., 2022).

A first 3D prototype including a hospital setting and an 89-year-old virtual patient were modeled and displayed on a large human-size screen (**Figure 3**). To provide a backstory, a patient file is displayed on the screen before the interaction starts. It includes medical information about the patient (i.e., name, age, diagnosis and medical history) and a description of the context before the interaction (e.g., restless night, refusal to eat) and the trainee's objective for the current scenario (e.g., stimulate the patient and ensure that the medication is taken).

Particular attention was paid to generating the *predominant competencies* of the VP, the implementation of the *underlying technology* through a WoZ simulation, the *evaluation of the tool* by trainees, and the *automatic monitoring of the users' behavior* (see **Figure 2**). Concretely, the VP could produce verbal (synthesized voice) and non-verbal (body and head movements, gaze direction, facial expressions) behaviors that mimicked an elderly patient with signs of Alzheimer's disease (apathy, memory loss, agitation, aggression, or refusal of care). The trainee could interact in natural language with the VP. In our simulation approach (**Figure 3**), the WoZ operator (a geriatric expert) selects the verbal and non-verbal behaviors (facial expressions, posture, etc.) to be generated in real time on the VP, based on the verbal and non-verbal behavior of the trainee who was expected to act as in a role-play with a real patient (Benamara et al., 2020). Each action performed by the WoZ to control the VP behavior is recorded and logged. After each session, the educational tool is assessed with questionnaires in terms of system usability, acceptability, VP realism and effectiveness of the educational tool.

In addition, a key aspect of the *VirtuAlz* platform relates to the automatic evaluation of the trainee's non-verbal behaviors, that are captured by a front-facing camera during the interaction with the VP that lasted on average 6 min. The corpus collected was composed of 29 videos of clinician-VP interactions (each video involved a different clinician, exercising at the geriatric hospital as a physician, psychologist, nurse, or health care provider). We focus our analysis on non-verbal features of the trainee using automated feature extraction. Several non-verbal cues have been shown to capture relevant socio-affective states in similar settings with children (e.g., Delaherche et al., 2013; Avril et al., 2014; Anzalone et al., 2019) or adults (e.g., Aigrain et al., 2016). The main difference with this line of research is that VirtuAlz focuses on the training of clinician to communicate with elderly patient with signs of Alzheimer's disease. Based on the literature mentioned in **Section 2.3**, we decided to focus on the analysis of the clinician's non-verbal behaviors by considering the following non-verbal cues: body posture (i.e., body openness, computed as the distance between wrists and shoulder of the clinician), proxemics (i.e., physical proximity with the VP), facial expressions based on facial Action Units analysis (i.e., smile with mouth corners pull, AU14—mouth corners depress, AU15—frowning with eyebrows lowered and drawn together, AU4—eyebrow/eyes raising AU1/AU5) or self-touching on the head (i.e., hand position in the zone of the head, see Aigrain et al. (2016). The facial Action Units (AUs) are automatically extracted by OpenFace (Baltrusaitis et al., 2018) while the features related to self-touching on the head, proxemics and body openness are computed from the Body and Hand pose estimation using OpenPose (Cao et al., 2021). This set of non-verbal cues is then transformed into symbols and evaluated throughout the interaction (for more details see Zagdoun et al., 2021) to obtain explainable measures that could be indicators of openness to others, warmth, or empathy (e.g., duration of the clinician's smiles, physical proximity or body opening during the interaction, see Mast and Hall (2017)) or discomfort or stress exhibited by the clinician (e.g., number of times the clinician touches their head, see Harrigan (1985). For the feedback, the symbols are contextualized by considering the behaviors of the virtual patient in order to assess the consistency of the clinician's behaviors (e.g., smiling when approaching the patient, do not appear nervous with over-gesturing or excessive self-touching). Although the potential of the VirtuAlz tool has not yet been fully realized, it offers the opportunity for trainees to work on their non-verbal behavior in safe environments. Although the potential of the VirtuAlz tool has not yet been fully realized, it offers the opportunity for trainees to work on their non-verbal behavior in safe environments. Results from the automatic analysis of non-verbal behavior should also allow, during interviews with a clinical educator, to provide finer-grained feedback aimed at encouraging the trainee to engage in self-reflection before interacting with a real patient.

## DISCUSSION

As mentioned above, the value of VP-based simulation is that it provides tools that allow clinical teams and researchers to examine and model the verbal and non-verbal behaviors of the clinician/student while manipulating either the social-emotional or cognitive behavior of the VP and the visual appearance of the graphic environments. With good experimental control, these features make VPs powerful, useful, and reliable tools for studying the social communication that is central to clinician-patient interactions. However, in the field of psychiatry and geriatrics (**Table 1**), research has mainly focused on modeling the VP to simulate specific clinical encounters or on the evaluation of the simulation tool itself (e.g., feasibility, credibility, usability). Among the 14 tools (17 articles) using VP simulation presented in this overview, five used simulation models (e.g., prerecorded videos associated with text-based interfaces) that do not allow for realistic human-like conversations (Carpenter et al., 2012; O'Brien et al., 2019; Shah et al., 2012; Cordar et al., 2014; Pantziaras et al., 2014, 2015). By contrast, four tools offer immersive experiences using VPs displayed on human-sized screens and interacting in natural language (Ochs et al., 2017, 2019; Dupuy et al., 2020; O'Rourke et al., 2020; Robinson et al., 2020). Note that while tools based on web interfaces or pre-recorded videos may lack realism and fluidity, tools based on natural language and speech recognition, are rarely fully autonomous and currently require the intervention of a human WoZ operator. In addition, our overview reveals a lack of interest in evaluating the learner. Note that in most of the studies, the learner evaluation in terms of knowledge is considered in post-session (except in, Carpenter et al., 2012; O'Brien et al., 2019; Orton and Mulhausen, 2008; Szilas et al., 2019). Interestingly, a few studies propose a follow-up of learners' knowledge several weeks after the interaction (Pantziaras et al., 2015) or an assessment of the transferability of the training to clinical practice (Liaw et al., 2020). By contrast, it was pointed out that an aspect seldom assessed was the learner's verbal (except, Parsons et al., 2008; Kenny et al., 2009a,b; Pantziaras et al., 2014, 2015; Dupuy et al., 2020) and non-verbal (except, Dupuy et al., 2020; O'Rourke et al., 2020; Liaw et al., 2020; Robinson et al., 2020) behaviors. Non-verbal behaviors play a crucial role in clinician-patient relationships (Henry et al., 2012). Eye contact, physical proximity, clinician's posture leaning toward the patient, or synchronization of the movements of this dyad may be associated with the length of the visit, the patient's perceived empathy, feeling of trust, or patient self-disclosure (Lorié et al., 2017; Goldstein et al., 2020). One possible reason for this poor consideration of non-verbal behaviors is that the tools used rely primarily on human coding (speech transcript, video annotation), which is time-consuming and labor-intensive (D'Agostino and Bylund, 2011) and highly subjective due to biases of human annotation (Mast and Cousin, 2013). A precursor to developing adequate simulation tools in clinical settings is being able to capture and analyze the user's non-verbal behaviors automatically so that they can be linked in real time to the patient's behavior or for ulterior feedback (e.g., focus group, exchange with a tutor). Such automatic methods (without requiring intensive human coding or specialized training) have already been validated for analyzing the clinician-patient relationship (e.g., Hart et al., 2016; Tan et al., 2020). More generally, we suggest that automated analysis of clinician-patient interaction could offer a high temporal resolution and fine-grained analysis–sometimes invisible to the clinician's or tutor's eye–to provide feedback to clinicians or students on key aspects of their communication. The link between such fine-grained analysis of interaction and learning gain of clinicians has to be investigated. A promising direction is to consider the concept of productive engagement as the level of engagement that maximizes learning Nasir et al. (2021). Lastly, these educational tools should consider the ethical issues surrounding virtual reality research (e.g., risks related to information overload, intensification of arousal with virtual environments and re-entry into the real world, Behr et al., 2005) or human-computer interaction (usefulness in the light of the purpose, Grinbaum et al., 2017; Wullenkord and Eyssel,

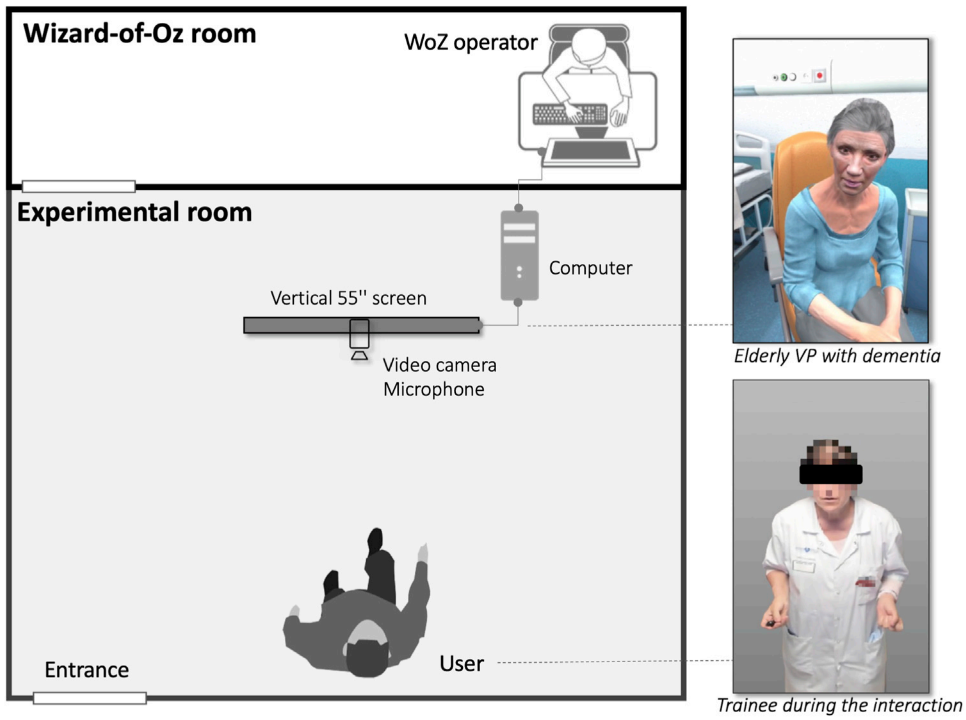


**FIGURE 3 |** Overall architecture of the VirtuAlz platform. Here a user (i.e., clinician) is instructed to interact in a face-to-face clinical encounter with Ms. Dupont, an elderly virtual patient (VP) with Alzheimer's disease symptoms. The 10-min interaction concerns taking medication and the VP exhibits behaviors such as agitation, aggression, apathy, or refusal of medication, and that the clinician must address (e.g., stimulate or pacify the patient) in order to persuade them to take their medication. The interface with the VP, including the hospital room, is displayed on a large screen (55′). The VP is controlled by a Wizard-of-Oz (WoZ) operator and equipped to record the user's non-verbal behaviors (i.e., through a video camera and microphone) to modulate the evolution of the interaction.

2020), and also protection of the user's data and privacy (e.g., audio/video recording of the learner, see Parsons, 2021).

## TOWARD BEST PRACTICES AND USES

Importantly, when developing a VP simulation tool, the pedagogical context has a strong impact on the choice of technologies needed to develop the modules for simulating the VP's verbal and non-verbal behaviors. Hence, a simulation tool that focuses on training nonverbal communication skills requires technologies to detect and interpret the trainee's nonverbal behavior (Hoque et al., 2013).

It should also be considered that one of the most challenging parts of any VP application is the development of modules for simulating verbal and nonverbal behaviors. According to the context, they may only require a small subset of non-verbal behaviors such as posture and gestures, without necessarily focusing on facial expressions or gaze (Ochs et al., 2018). However, if the prime pedagogical objective is rather directed to the verbal content of communication or decision-making, a chatbot or a text-based interface may be suitable (Tanaka et al., 2017a).

At the same time, the choices regarding the technologies to be used are dependent on the resources and constraints of the project. Computer screen simulation can provide a multisensory and immersive interactive experience, with the possibility to design a VP that communicates verbally and nonverbally in real time. Alternatively, if the simulation needs to run on smartphones or tablets, technical resources are limited, and heavy computations cannot always be performed (e.g. real-time detection of non-verbal behavior). In such cases, the simulation will rely instead on text and graphical menu interfaces and use predefined animations to control the VP's behavior (Philip et al., 2020).

It also has to be mentioned that several different technologies are available for simulating verbal and nonverbal VP behaviors. In most simulation systems in medical training, a decision tree is used to guide the interaction and trigger the VP's reactions depending on the trainee's choices and/or behavior. The possible VP reactions depends on the specific needs of the simulation, and can display specific characteristics of an agent, such as emotional states or pathological symptoms (Rizzo and Shilling, 2017). These reactions can be triggered from a predefined set of combinations of verbal and non-verbal behaviors, following the unfolding of the scenario script. VP's reactions can also be selected in real-time by a human experimenter using a wizard-of-oz setup according to the specific goals of the training. Finally, VP reactions can be generated automatically using computational models that take into account a set of inputs provided by the user (for a review, see Wang and Ruiz, 2021). From a technical point of view, this latter technique is the most challenging to design. A first category of simulation is based on theories of cognitive psychology and allows emulating emotional states or a personality appropriate for a given context (Jones and Sabouret, 2013; DeVault et al., 2014), or even pathological symptoms (Benamara et al., 2022). A second category of simulation focuses on the verbal content of the interaction and allows interaction with the VP through natural language. In this context, speech-based facial animation can be synthesized from keywords or automatically with machine learning methods. Note that most systems are hybrid, incorporating both emotional models and natural language-based techniques (Vougioukas et al., 2020). In the future, additional non-verbal behaviors could be explored to improve the simulation of social interaction in medical environments. For instance, in medical care, the use of touch plays a crucial role in communicating with patients (Kim and Buschmann, 1999). Thus, the development of haptic interfaces should provide new ways to train social skills related to social touch (for a review, see Pelachaud et al., 2021).

In conclusion, the survey of the literature enables us to propose concrete recommendations for each step of the VP simulation process, including the development of the VP, conduct and evaluation of the training sessions. Designers will be expected to include healthcare professionals in all stages of the VP design in order to develop and implement a VP tailored to their needs and to define ways to improve the tool.

Virtual patient (VP) development.

- *Use cases*–Determine clinical cases that are challenging for clinician/student and patient interactions, and identify learner populations that might be interested in or benefit from training.
- *Needs*–Examine the needs of learners, particularly in difficult situations, by reviewing the literature and conducting field observations in clinical units, interviews and questionnaires.
- *VP*–Design a VP adapted to the needs and constraints of the project. On smartphones/tablets, the VP should be based on predefined animations. On computer screen the VP should be able to communicate autonomously verbally (e.g., question-answer) and non-verbally (e.g., facial expressions, gaze, body movements, gestures, prosody), to promote immersion (taking into account screen size) and human-like interactions.
- *Scenario*–Develop a narrative scenario, which may include problem-solving and allow multiple training sessions. A non-linear navigation structure (in which the learner's decisions shape the VP's behavior) will ensure flexibility and learner interactivity with the VP.
- *Feedback*–Provide feedback with messages, scores, visual representation of the VP's emotional state. Gamification with leaderboards could help make the learning experience fun and engaging.
- *Choices and tradeoffs*–Review the available technology solutions for VP simulation and choose the one that seems to best meet the needs of the learners in terms of accessibility, usability, training needs, cost, data security and privacy, technical assistance requirements and sustainability. Authoring tools, if available, could help design, prototype, and deploy VPs in a variety of use cases.
- *Feasibility/Usability testing*–Test the feasibility of the system with learners, conduct usability testing, and define necessary adaptations of the tool.

Conduct and Assessment of training sessions.

- *Training plan*–Establish a training program (where and when to use VP simulation) that is tailored to the needs and abilities of the clinicians or students who will be involved in the learning.
- *Tutorial*–Offer specific training on the use of the tool for learners interested in participating in the learning experience. The availability of educational material adapted to this objective (e.g., tutorials) can help to enhance understanding of the tool's use.
- *Debriefing*–Conduct VP learning sessions followed by debriefing with a tutor at the end of the session to allow learners to discuss the use case and ask questions.
- *Training effectiveness*–Evaluate the learning gain pre- and post-session with questionnaires.
- *Non-verbal communication*–Provide tools to measure and interpret non-verbal characteristics of clinician-patient communication. An automated or semi-automated tool (commercial software) for measuring and analyzing non-verbal communication can provide additional value over manual annotation.
- *Follow-up*–Define a way to follow-up on the VP learning at the individual and institutional level (university, hospital) to identify necessary modifications.

## AUTHOR CONTRIBUTIONS

LC and MC contributed to the conception and planning of the overview LC identified articles relevant to the topic and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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Regis Kopper,
University of North Carolina at Greensboro, United States

REVIEWED BY
Fernando Marmolejo-Ramos,
University of South Australia, Australia

*CORRESPONDENCE
A. Oker,
ali.oker@univ-reims.fr

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# Embodied social cognition investigated with virtual agents: The infinite loop between social brain and virtual reality

A. Oker*

France Laboratoire C2S (Cognition, Santé, Société) EA6291, Université de Reims Champagne Ardenne, Reims, France

While the debate regarding the embodied nature of human cognition is still a research interest in cognitive science and epistemology, recent findings in neuroscience suggest that cognitive processes involved in social interaction are based on the simulation of others' cognitive states and ours as well. However, until recently most research in social cognition continues to study mental processes in social interaction deliberately isolated from each other following 19th century's scientific reductionism. Lately, it has been proposed that social cognition, being emerged in interactive situations, cannot be fully understood with experimental paradigms and stimuli which put the subjects in a passive stance towards social stimuli. Moreover, social neuroscience seems to concur with the idea that a simulation process of possible outcomes of social interaction occurs before the action can take place. In this "perspective" article, we propose that in the light of past and current research in social neuroscience regarding the implications of mirror neuron system and empathy altogether, these findings can be interpreted as a framework for embodied social cognition. We also propose that if the simulation process for the mentalization network works in ubiquity with the mirror neuron system, human experimentations for facial recognition and empathy need a new kind of stimuli. After a presentation of embodied social cognition, we will discuss the future of methodological prerequisites of social cognition studies in this area. On the matter, we will argue that the affective and reactive virtual agents are at the center in conducting such research.

KEYWORDS

**embodied social cognition, virtual agents, social brain, social interaction, affective cognition**

## Introduction

We owe to Fodor (1983), one of the most eminent propositions of a functional topography of cognitive mechanisms underlying behavior. By proposing the modularity of mind, Fodor (1983) acknowledged that there are different levels of information processing such as input-system and higher-level processing. According to this, input-system level would be modular, which means self-contained modules representing lower-level object-identification (perceptual, linguistic, or other) whereas higher level such as reasoning would be without any specific modules.

This view of human cognition had an impact on the scholars to study solely module centric expressions of human cognition, from a symbolic point of view until the advent of embodied cognition as a new proposition of the human mind. Therefore, before embodied cognition became a new framework for studying the human mind, cognitive sciences have had a longtime experience on scientific reductionism. It tends to study and describe mental processes underlying conscious or unconscious behavior by creating experimental situations which allows excluding various factors and stimuli by leaving only one or a few of interest just to be interested primarily to input-system level modules.

Contrarily, the embodied cognition defines the human cognition being holistically situated, being a part of the physical world, grounded in mechanisms that evolved for interaction with the environment and utterly using action for receiving input and as a response (Wilson, 2002). On the matter, it has been already proposed that even in the case of abstract domains, such as concepts and metaphors, there is always sensorimotor properties associated with them. The simulation system seems to be a key component in manipulating concepts, not only related to sensorimotor representations but also intentions and beliefs, which are components of social cognition (for a review see Marmolejo-Ramos et al., 2017).

The study of social cognition has also suffered from the main paradigm that prevails until now: features composing social cognition have been investigated by separating psychological constructs and by designing paradigms that require the observation and interpretation of a unique social stimulus. The most documented constructs such as theory of mind, empathy and emotion recognition have been tested by presenting picture stimuli, drawings, or videos that place the subject in a passive stance adopting the third person perspective. Such an approach was criticized by Schilbach et al. (2013): "social cognition is fundamentally different when we are emotionally engaged with someone as compared to adopting an attitude of detachment and when we are interacting with someone as compared to merely observing her" (pg. 396).

In line with this claim, we will consider in this perspective paper that the phenomena of interpersonal interaction as central to research in social cognition and assume that they should not be reduced to the separated constructs cited above. Moreover, following the advent of embodied cognition, we will show that new intersubjective stimuli, namely virtual agents, can be proposed for studying embodied social cognition. Firstly, we will present what is called embodied social cognition, following the neuroscientific evidence in the literature. Finally, we will show why and how affective virtual agents seem to be a tailor-made technology in the service embodied social cognition framework, but more particularly for psychiatry and mental health studies.

## Embodied social cognition

Embodied Social Cognition as a theoretical construct followed the emergence of embodied cognition which is a great rupture from Fodor's (1983) view of human cognition. In embodied cognition, some authors such as Clark (1997); cited by Chemero, 2011) favors a radical approach, claims that there is no abstract information processing between perceptual features of the object and its symbolic representation and thus, it is inconceivable to separate action and perception in bodily experience. Moreover, in this view, the cognition is also enactive, a concept proposed by Varela et al. (1991) which states that our understanding of an object in a given environment is solely determined by mutual interactions between the organism (and its neuropsychological functioning) and the environment. Thus, phenomenologically, the sense that we attribute to the objects is not a result of an abstraction process from visual features to a representation but an enactment of bodily activities. Moreover, according to Wilson (2002), embodied cognition is situated; it "involves interaction with the thing that the cognitive activity is about. . .in the context of task-relevant inputs and outputs" (pg. 626). This would suggest that cognitive activity is always "on-line" with the features regarding the elements of the environment, the action-perception coupling, and the bodily experience by a simulation process (Wilson, 2002).

Naturally, the idea of applying embodied cognition framework in the field of social cognition has been proposed in the last 15 years. For instance, Gallese (2007) paved the way by proposing that the mirror neuron system in monkeys and humans and the simulation (Gallese and Sinigaglia, 2011) can be accounted for embodied social cognition framework. The mirror neuron system has been discovered in the 90's within the ventral premotor cortex of the macaque monkey (Di Pellegrino et al., 1992; Gallese et al., 1996), although today, its subsequent areas is still a research interest (for a review see, Kilner and Lemon, 2013). This neuron network was found implicated when a monkey performs an action such as grasping and when monkey just observes another one performing a similar action (Di Pellegrino et al., 1992; Gallese et al., 1996), thus called the mirror neuron system (for a review, see Rizolatti et al., 2001). The extent of MNS (mirror network system) in humans seems to be broader: implicating human inferior frontal gyrus (IFG), (Parsons et al., 1995; also see Keysers and Gazzola, 2006). According to Oberman et al. (2007), the MNS works in line with superior temporal sulcus (known also for facial expression recognition, see Iacoboni et al., 2001); inferior parietal lobule (known also for body image, Buccino et al., 2001); and the limbic system (known also for emotion; Singer et al., 2004). According to Oberman et al. (2007) these systems altogether "may play a key role in multiple aspects of social cognition from biological action perception to empathy" (pg. 62). However, as Heyes et al. (2022) proposed, the MNS framework in social cognition seems to lose interest of scholar the last decade, however there is "still much to be discovered about the sources and developmental timing of the sensorimotor experience that builds mirror neurons and how this information might be used for clinical and educational interventions" (pg. 162).

If social cognition has been identified by any cognitive process "that involves conspecifics, either at a group level or on a one-to-one basis" (Blakemore et al., 2004, pg. 216), according to these authors, understanding others' actions, intentions, and emotions, also called mentalization, is a key object in social cognition. Indeed, other authors such as Van Overwalle and Baetens (2009) and Iacobonu et al. (2005) propose that there is a cooperation between MNS and the mentalizing network (the precuneus, the temporo-parietal junction and the medial prefrontal cortex), by the fact that the MNS provides crucial information to the mentalizing network particularly when moving parts of a body is observed[1].

Moreover, it seems that there is another cooperation between MNS and emotion recognition (Bastiaansen et al., 2009). According to these authors, motor simulation may be a trigger for the simulation of associated feeling states. In other words, simulation of other people's facial configuration and imitation can trigger pertinent emotional states. This proposition is in line with the work of Niedenthal et al. (2001) which reported that blocking facial mimicry leads to a slower detection of facial expression. Bastiaansen et al. (2009) concludes that "regions involved in stimulating facial expressions indeed seem to trigger an affective simulation of the hidden inner states of others" (pg. 2397). On the subject, it is worth mentioning that Holstege et al. (1996) reports a case study with a patient having a small infarction in the white matter which interrupted the corticobulbar fibers originating in the face part of the motor cortex. Holstege et al. (1996) highlights the fact that the patient, although unable to use oral muscles on her left side of the mouth voluntarily, was able use the same muscles when she reacts spontaneously to a joke or a funny remark. According to Holstege et al. (1996), this should provide an argument for the existence of two distinct motor systems, one voluntary and other emotional (the latter can also be characterized as automatic).

Regarding recognition other's facial expressions, Van der Gaag et al. (2007), proposed that the MNS can, in concert with the limbic regions and somatosensory system, become active during the monitoring of facial expressions as well as the production of similar facial expressions. However, whether the mimicry plays a central role in emotion recognition is still a research topic (see Niedenthal et al., 2010), for instance "people with bilateral facial paralysis stemming from Moebius syndrome can categorize the facial expressions of others without difficulty" according to Rives Bogart and Matsumoto (2010), cited by Morsella et al., 2010; pg. 456). Moreover, mimicry (or lack thereof) has already been studied in neuroatypical children with the use of virtual agents as a stimulus (Forbes et al., 2016).

## Studying embodied social cognition with virtual agents

Affective and reactive virtual agents have the ability to simulate human behaviors, and to present stimuli that trigger social interaction while providing a strong degree of experimental control and reproducibility (Wilms et al., 2010). The opportunity of using virtual agents, also called embodied conversational agents—ECA (Cassell et al., 2001), has been highlighted by Gratch (2014). According to Gratch (2014), virtual agents simulate embodied aspects of human behavior, particularly in non-verbal behavior. In this section, we will present how and why virtual agents and virtual characters are part of virtual reality and virtual environments, then how they can be an asset in the field of cognitive psychopathology.

### Virtual agents provide interaction

Until last decade, all studies conducted before used either static stimuli such as photographs or dynamic stimuli such as movie clips provided by actors expressing an emotion but, in every situation, participants are inactive and mere observers. Researchers point out that studying the recognition of emotions with static images is not consistent with what happens in everyday life (Isaacowitz and Stanley, 2011). Emotional recognition and contextualization of emotion in a discourse are dynamic processes, integrating several sensory modalities, where both interlocutors are active, and not in a situation where the participant is a passive observer as previous studies presented in social cognition. Recently, the importance of interactive and immersive environments for investigating social cognition has been highlighted (Zaki and Ochsner, 2009; Schilbach et al., 2013). Schilbach et al. (2013) advocate the idea of using social interactions to study social behaviors and knowledge (including recognition) because, in their view, there is a difference between observing an interaction and participating in the interaction. Participating in social interaction involves emotional engagement, which is displaced from traditional emotional recognition tasks (Schilbach et al., 2013).

For example, one study conducted by affective and reactive virtual agents showed that ocular strategies in social cognition for information gathering are different whether the experimental setting is interactive or not and whether healthy aging individuals listen or answer (Pavic et al., 2021) to the question asked by virtual avatars animated by a platform named "Virtual Interactive Behaviour" (Pecune et al., 2014). Another example

1 This might also be the case of bodily expressions of emotions, as De Gelder et al. (2004) described.

Giraud et al. (2021) present a design of a virtual interactive system in which a virtual agent plays a mediator role for the training of children with autism spectrum disorder (ASD). The proposed system is composed of a virtual character projected onto a surface on which a tangible object is magnetized: both the user and the anthropomorphic virtual character hold the object, thus simulating a joint action. Although realizing a joint action is a difficult task for children with ASD, preliminary feedback from this study is encouraging.

## Virtual agents provide automatic immersion

As pointed out by Pan and Hamilton (2018), virtual reality is not just "things viewed in a head-mounted display' but means among other things 'a computer-generated world" (pg.395). Of course, virtual agents can be a part of words presented in a head-mounted display, however, this is not why they provide immersion and interaction to the user. Regarding immersion, it should be noted that arguments presented above regarding the MNS explain why the sole presentation of a real emotional face triggers simulation in cognitive system. Regarding automatic immersion provided by virtual agents, there is a largely known phenomenon called 'The Uncanny Valley' proposed by Masahiro Mori, 1970. According to Mori (1970), humanlike objects, such as robots, provoke positive emotional responses according to their degree of human likeness. However, at some point, when a certain degree of likeness is reached, the humanlike object is qualified by being repulsive. Among several explanations of this phenomenon, one is of importance for the main contribution of this paper: components of social cognition but particularly empathy would be involved when visualizing inanimate objects depicting humans (Misselhorn, 2009; Stein and Ohler, 2017).

However, it can be proposed that virtual agents being an 3D graphical animation, the immersion that they provide are lesser than the real humans. On the contrary, it is worth noting that most advanced virtual agent platforms simulation of emotional facial expressions are based on real human facial muscle contractions by a taxonomy provided by the works of Paul Ekman. The relevance of ECA's is that they allow researchers to manipulate the action units which are supposed to be universal and based on the actual human facial muscle contractions (Ekman and Friesen, 1978; Ekman, 2002). Ekman and Friesen (1978) proposed the idea that there would be prototypical features for expressions of which some of them would be also universal (Ekman, 1994). To this end, Ekman and Friesen (1978) also proposed a taxonomic system of facial muscles named FACS (Facial Action Coding System) which would standardize physical expression of emotions. These 44 codes called "Action Units" are what is being used to animate most conversational virtual agents today, but not all. In fact, these authors used largely (but not only) the description of human facial muscles described by Darwin in 1872. In the book "the expression of the emotions in man and animals," Darwin (1872) depicted the facial muscles involved in the facial expressions. Although the animation of action units in virtual environments can differ because of the technology used, it can be proposed that the simultaneous use of these units within different intensities can create more than 7.000 different combinations (Scherer and Ekman, 1982). For instance, one of these ECA's namely MARC (Multimodal Affective and Reactive Characters) framework (Courgeon et al., 2008; Courgeon and Clavel, 2013) can be used to animate a realistic 3D character. It is a software of virtual agents capable of expressing emotions through facial expressions while interacting with the user, based on actions units. MARC is a multi-character animation platform including body and facial animations in real-time. Its architecture is composed by 3 modules: 3D animation software interactive in real time, an offline editor of facial expressions and an offline body animation editor (see Figure 1).

Finally, the embodied point of view of social cognition assumes that intentionality and perception cannot be explained apart from the action that accompanies it (Barsalou, 2009). This is also the case for the spontaneous discourse comprehension and inferences which can be made through the same simulation process of actions (Cevasco and Marmolejo-Ramos, 2013). According to the embodied social cognition, we could understand the intentionality of the other only with internal simulation, which is an automatic and nonconscious reconstitution of events. This reconstruction may be possible only if the virtual agent has the same physical characteristics with us, like the same facial muscle contractions and if these muscle contractions have a meaning in the context of events. Thus, our claim is that the use of embodied conversational agents animated with the action units are tailor-made stimuli for affective cognitive sciences studies. The use of the same human facial muscles can trigger the MNS more directly and automatically than any other stimuli, and the fact that virtual agents can adapt their behavior in accordance with user's input makes them situated which (which is a prerequisite of embodied social cognition) cannot be done with videos or animations.

## Virtual agents are tailored-made stimuli for affective cognitive sciences and mental health studies

One of the biggest issues in experimental research on affective cognitive sciences is the difficulty to design interactive paradigms that are, at the same time, ecological, controlled, and reproducible. Progress in affective computing is overcoming these constraints. Embodied conversational agents—ECA (Cassell et al., 2001) are at the center of all the

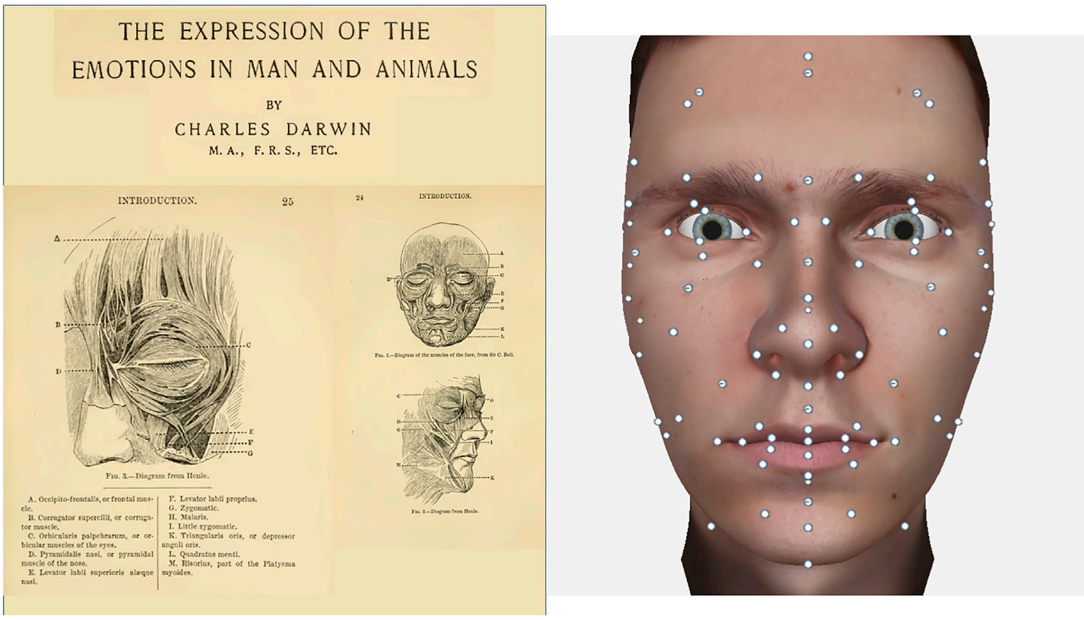


FIGURE 1
On the left, original pictures of Darwin's "the expression of the emotions in man an animals" in 1872; on the right, an example of embodied conversational agents with the action units presented on the neutral model, offering to be activated with several intensity (Courgeon et al., 2008; Courgeon and Clavel, 2013).

requirements: They can simulate human intelligence, communicate by expressing affects *via* facial expressions and affective prosody, react according to user's actions, and contextualize a human interaction. Thus, ECAs can be used in facial expression experiments, (Grynszpan et al., 2011; Marcos-Pablos et al., 2016). For instance, Grynszpan et al. (2011) showed that when interacting with a virtual agent, people with high functioning autism spectrum disorders showed a weaker modulation of eye movements, suggesting impairments in self-monitoring of gaze (for a debate regarding the autism and MNS see Heyes et al., 2022). Interesting enough, in Marcos-Pablos et al. (2016), although people with schizophrenia globally present deficits in the recognition of facial expressions, they showed that patients outperform the control group in the recognition of happiness when they are dealing with the virtual agent expressing happiness.

Other attempts for investigating facial expressions recognition, empathy, and intentionality performance in psychiatry with the use of ECA's have been made (Oker et al., 2015; Barrada-Baby et al., 2016). Oker et al. (2015) evaluated whether a virtual card game with affective and reactive virtual agents can be proposed to people with schizophrenia. In their study created with MARC platform presented above, people suffering from schizophrenia were presented a game in which they met a female virtual agent and had to infer from her facial expression displays which card to choose to match the color of another card. They suggest that the interaction with virtual agents can be fully functional with patients with schizophrenia. Another study showed that patients with schizophrenia are less prone to interpret virtual characters empathetic questioning as helpful during an interaction following the same virtual card game (Berrada-Baby et al., 2016).

Moreover, although this is beyond the scope of this paper, virtual reality and virtual avatars have also been proposed as cue-exposure therapy for substance use disorders (Hone-Blanchet et al., 2014). Other studies with virtual agents interested in social anxiety (Kiser et al., 2022), social phobia (Ruch et al., 2014) or assessment of depression and anxiety (Egede et al., 2021). Regarding mental health issues and therapeutic interventions which can be made by virtual agents, one cannot ignore that unparalleled advances have been made in the field of emotional artificial intelligence. Emotional AI is a term for artificial intelligence as a biologically inspired cognitive architecture which can interact with people according to their emotions. These emotions can be gathered for instance by facial expression configurations (Ko, 2018) displayed during interaction. As such, if implemented to virtual agents, they can adapt their behavior, discourse, and facial expressions according to the user's mood and induced emotional states, allowing them to adapt their behavior autonomously to motivate them and obtain a more engaging social interaction (Rodríguez and Ramos, 2014; Barrett et al., 2019) which could have more successful therapeutic outcomes.

In conclusion, to perform a functional social interaction, the importance of interpreting others' emotional states, needs and desires is well documented (Beer and Ochsner, 2006; Frith and Frith, 2012). These emotional states can be mostly interpreted by facial expression recognition (Izard, 2001; Kohler et al., 2002) and the direction of one's gaze (Pfeiffer et al., 2013). People who have difficulties to process and integrate all this information have been reported to be impaired in social interactions and quality of life, such as depression and social isolation. In the literature, these impairments in the adults have been reported mostly in schizophrenia (Brüne, 2005; Penn et al., 2008), schizotypy (Wang et al., 2015), but also in aging individuals (Chaby and Narme, 2009; Ziaei et al., 2016). The use of virtual agents can achieve a huge leap by taking advantage of human neurology in an attempt to understand, evaluate and rehabilitate these pathologies more efficiently than any other stimuli.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

## Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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