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The Presence of Fear: How Subjective Fear, Not Physiological Changes, Shapes the Experience of Presence

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When we become engrossed in novels, films, games, or even our own wandering thoughts, we can feel present in a reality distinct from the real world. Although this subjective sense of presence is, presumably, a ubiquitous aspect of conscious experience, the mechanisms that produce it are unknown. Correlational studies conducted in virtual reality have shown that we feel more present when we are afraid, motivating claims that physiological changes contribute to presence; however, such causal claims remain to be evaluated. Here, we report two experiments that test the causal role of subjective and physiological components of fear (i.e., activation of the sympathetic nervous system) in generating presence. In Study 1, we validated a virtual reality simulation capable of inducing fear. Participants rated their emotions while they crossed a wooden plank that appeared to be suspended above a city street; at the same time, we recorded heart rate and skin conductance levels. Height exposure increased ratings of fear, presence, and both measures of sympathetic activation. Although presence and fear ratings were correlated during height exposure, presence and sympathetic activation were unrelated. In Study 2, we manipulated whether the plank appeared at height or at ground level. We also captured participants' movements, which revealed that alongside increases in subjective fear, presence, and sympathetic activation, participants also moved more slowly at height relative to controls. Using a mediational approach, we found that the relationship between height exposure and presence on the plank was fully mediated by self-reported fear, and not by sympathetic activation.

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Public Significance Statement
Presence is the feeling of being physically situated in the world. Previous studies report that people are more "present" when experiencing intense emotions. We used a fear-inducing virtual reality simulation to show that presence is related to the feeling of fear, but not to the increases in heart rate or sweating that accompany it. Our findings help us to understand how the mind and body make us feel present.

Keywords: emotion, virtual reality, fear, presence, psychophysiology

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Although it may feel like we directly perceive the world through our senses, our brains construct and update our current reality based on its best predictions given the information available (Barkow et al., 1996; Barrett, 2017; Seth, 2015; Tsakiris, 2017). Part of this construction includes presence—a metacognitive subjective feeling that one is physically situated within some reality (Dokic & Martin, 2017; Lombard & Ditton, 1997). Although we may not typically reflect on our presence in the physical world, we know that we can feel more-or-less present in different realities: in dreams (Metzinger, 2003; Windt & Metzinger, 2007; Windt, 2018), through immersion in film, literature, or music (Bracken, 2005; Mehr et al., 2019), and in dissociative states associated with trauma, certain drugs, psychosis, and other psychopathologies (Hunter et al., 2003; Sierra & David, 2011; Singh, 2018). It is also common for presence to wax and wane in normal waking life as we concentrate or daydream (Andrillon et al., 2019; Kane et al., 2007; Schooler et al., 2011), and for awareness of our physical bodies to fluctuate in association with changes in hunger, pain, sexual arousal, or emotional states (Craig, 2009).

Very little is known, however, about the psychological mechanisms that give rise to presence, in part because the phenomenon has proven difficult to study. No gold-standard measure of presence currently exists and attempts to identify potential physiological and behavioral correlates of presence have produced mixed findings (Bailey et al., 2009; Gorini et al., 2011; Meehan et al., 2002, 2005; Sanchez-Vives & Slater, 2005; Wiederhold et al., 1998). Aside from the methodological challenges associated with assessing any subjective state, presence is also difficult to manipulate within physical reality. Technological advances in immersive virtual reality, however, make it possible for people to feel present in experimenter-controlled simulated environments, despite knowing that they are, in fact, situated in physical reality. Indeed, the goal of virtual reality developers is to maximize presence via high-fidelity multisensory inputs and responsive interaction schemes that create the feeling of "being in" the virtual world (Cummings & Bailenson, 2016; Sanchez-Vives & Slater, 2005; Slater et al., 2009). Virtual reality research has primarily focused on the technological features of a virtual reality system that enhance presence (e.g., field of view, visual resolution, multisensory inputs). Although such technological (i.e., immersive) factors putatively support presence, studies manipulating these variables have reported weak effects on participants' reports of their experiences (Gromer et al., 2019; Usoh et al., 2000; Zimmons & Panter, 2003).

Virtual reality affords researchers the ability to study psychological factors that may give rise to presence. For instance, alongside the induction of presence, contemporary virtual reality systems have successfully induced a range of authentic emotional states (Bernardo et al., 2021; Chirico & Gaggioli, 2019; Chirico et al., 2018; Collange & Guegan, 2020; Diemer et al., 2015; Felnhofer et al., 2015; Kisker et al., 2021). In clinical contexts, virtual reality has been used effectively to deliver exposure therapy, a treatment that depends on its ability to provoke fear and anxiety (see the meta-analysis by Wechsler et al., 2019). In nonclinical contexts, simulations that involve heights or threatening animals such as spiders (Brice et al., 2021) induce strong fear responses that include subjective feelings of fear, physiological changes consistent with activation of the sympathetic branch of the autonomic nervous system (e.g., increased heart rate [HR] and skin conductance; Gromer et al., 2019), and behavioral responses consistent with caution (Kisker et al., 2021). Interestingly, it has been repeatedly demonstrated that fear (or anxiety) experienced in virtual reality positively correlates with presence (Alsina-Jurnet et al., 2011; Bouchard et al., 2008; Ling et al., 2014; Peperkorn & Mühlberger, 2013; Peperkorn et al., 2015; Price & Anderson, 2007; Price et al., 2011; Riva et al., 2007; Robillard et al., 2003), leading some to propose that emotional experiences (fear, in particular) may be causally linked to presence (Price et al., 2011).

How might fear (or indeed any emotional state) make one more present in the physical world? Emotional states comprise three dissociable, but interrelated components: subjective feelings, physiological changes, and behavioral action tendencies (Kreibig, 2010; Lang, 1995; Mauss & Robinson, 2009). In fear, for example, subjective feelings are accompanied by activation of the sympathetic nervous system (as indicated by increases in HR and sweating), and priming of defensive behaviors (fight, flight, or freeze). Several prominent theories of emotion—dating to James (1884)—posit a primary role for the body in generating emotions (Barrett & Lindquist, 2008; Lang, 1995; Niedenthal et al., 2014). Although they vary in the specified mechanisms, all embodied theories of emotion propose that physiological changes in response to environmental challenges generate interoceptive signals (i.e., afferent signals that allow for the perception of the physiological condition of the body; Critchley & Garfinkel, 2017) that are interpreted by the brain (in light of context, meaning, and memory) to create emotional feelings and to prime adaptive behaviors (Critchley & Garfinkel, 2017; Garfinkel & Critchley, 2016; Tsakiris, 2017). Within this framework, fear can be described as a subjective feeling that arises when sympathetic activation aligns with our appraisal of a current threat.

A similar process of interoceptive attribution has been proposed as the mechanism underlying presence. For example, Seth et al. (2012) have proposed an interoceptive predictive coding model that theorizes that we feel present when our interpretation of a situation is aligned with our physiological state. A connection between presence and interoception is also supported by neural evidence showing that the anterior insular cortex (the primary neural target of afferent signals that give rise to interoception) is also a key component of the network that underpins awareness of ourselves, others, and the environment (Craig, 2009). Following from these perspectives, it stands to reason that we experience presence when changes to our physiological state align with the expected physiological change associated with a perceived environment. Importantly, Seth et al. (2012) argue that presence is evoked directly by physiological signals generated by the autonomic nervous system (e.g., changes in HR, respiration, or sweating), and indirectly by other body responses (such as defensive behaviors) that are consistent with the environment.

Diemer et al. (2015) applied Seth's model to explore the causes of presence experienced in virtual reality. Their interoceptive attribution model highlights two sources of information that inform judgments about how present one feels when in virtual reality. The first factor relates to the immersive properties of the virtual reality system presenting the simulation; the second factor is the extent to which that simulation activates the autonomic system. If autonomic activation is key, then one would expect the experience of presence to be causally linked to autonomic changes in the body rather than to subjective emotional experience per se (e.g., feelings of fear).

Current evidence linking presence to emotional experiences comes largely from correlational studies in which increases in subjective emotional experience and physiological changes are positively correlated with increases in presence. However, correlational evidence is unable to clarify whether presence is a direct consequence of sympathetic activation or of the subjective emotional experience only. Studies that experimentally manipulate emotions are required to establish the causal contributions of subjective and/or physiological changes to the experience of presence.

Several recent experimental studies have shown that height simulations in virtual reality induce subjective, physiological, and behavioral changes consistent with authentic fear (Gromer et al., 2019; Kisker et al., 2021), even though participants are aware that they are in no physical danger. These findings are consistent with other studies showing that place and plausibility illusions in a wide range of virtual environments can induce realistic responses (Slater, 2009). These studies also show that participants at height (relative to a control condition at ground level) report greater presence. For example, Kisker et al. (2021) found that participants who walked a virtual plank at height showed increased HR and slower walking times during the simulation and reported increased negative affect and greater presence after the simulation. Similarly, Gromer et al. (2019) immersed participants in a virtual environment in which they stood at the edge of a cliff, which increased online ratings of fear, presence, and sympathetic activation (HR and skin conductance) relative to a control condition.

These findings indicate that fear and presence covary, but they do not shed light on the mechanism through which height exposure increases presence. One way to do this is by using an experimental mediation approach (Koschate-Fisher & Schwille, 2021). In experimental mediation, a causal relationship can be established between a manipulated independent variable and an outcome. Intermediary variables can then be tested as potential mediators of the relationship. In the current study, we use experimental mediation to determine whether the effect of height on presence is mediated by sympathetic activation, changes in the subjective experience of fear, or both.

In the following studies, participants in virtual reality walked on a wooden plank that appeared to be suspended 80 stories above the ground. In Study 1, participants reported emotional experiences and feelings of presence while we recorded HR and skin conductance, allowing us to test relationships among presence, fear, and sympathetic activation. In line with previous research, we expected heights to be associated with increased ratings of subjective fear and presence and increases in HR and skin conductance level (SCL). In Study 2, a control condition was added in which participants walked the same plank at ground level, allowing us to isolate the effect of height exposure and to determine whether subjective or physiological indices of fear mediate the effect of height on presence. If interoceptive accounts (Diemer et al., 2015; Seth et al., 2012) are correct, then the effect of height exposure on presence should be mediated by changes in HR and SCL. Alternatively, if presence is driven by subjective feelings, then the effect of height on presence should be mediated by changes in self-reported fear.

Study 1

The primary aim of Study 1 was to ensure that the height simulation effectively induced fear and to establish relationships among presence, fear, and sympathetic activation. All participants provided emotion and presence ratings at several points within the plank-walk simulation, while we also recorded HR and SCL.

Method

Participants

Sixty-five undergraduate participants studying first-year psychology took part in the study in exchange for course credit (42 female, 19 male, zero nonbinary, ages 18–53 years; $M = 20.4$, $SD = 5.6$). Demographic information was obtained using a questionnaire administered on a desktop computer. Participants were asked to respond to a free-response box which asked "what's your gender?" and another free-response box which asked "How old are you?" Information about participants' ethnicity was not collected. Following the application of exclusion criteria (see the Data Preparation and Exclusions section below), the final sample size submitted for analyses was 58. Participants were right handed, with no known hearing impairments, normal or corrected-to-normal vision, limited experience with virtual reality, no current diagnosis of depression or anxiety, and no history of neurological disorder. All participants reported having never experienced the simulation before participating. The sample size target of 65 participants was determined using G*Power (Faul et al., 2007). The estimated bivariate correlation was based on the most conservative effect reported by Gromer et al. (2019), who found a correlation between fear and presence of $r = .42$ in their "low sensory realism" height condition. This sample size allows us to detect an effect of this size with greater than 90% power. Both Studies 1 and 2 were approved by the Human Ethics Committee, Victoria University of Wellington. The ethical approval of these studies is in accordance with the Helsinki declaration. All participants provided informed consent before participation.

Materials and Apparatus

Virtual Reality System and Simulation. The virtual reality height scenario used in Study 1 was the virtual reality game "Richie's Plank Experience" (Toast, 2017). The simulation was obtained from the Steam online store and was run using SteamVR. In the scenario, participants have the ability to navigate a city street, enter and operate the elevator of a tall building, and walk along a wooden plank at a height of 80 stories. An actual wooden plank (19 cm × 202 cm) was placed on the floor to enhance the plank-walking haptic simulation.

The virtual reality simulation was presented via an High Tech Computer (HTC) Vive virtual reality headset. Two HTC Vive Base Stations were positioned at opposite corners of a rectangular room (3.6 m long and 2.9 m wide). The base stations were suspended at a height of 2.44 m and spaced 4.62 m apart. Participants carried an HTC Vive controller in their right hand which allowed them to interact with a virtual button in the simulation. The virtual reality headset was connected to a desktop computer using a 5-m HTC Vive 3-in-1 cable. The virtual reality system was driven by a Windows 10 64-bit machine with an ASUS ROG Strix GeForce GTX 1,080 graphics card, 110 GB SSDs, 16 GB RAMs; Intel Core i7-7700 CPU @ 3.60 GHz.

Physiological Measures. Measures of sympathetic activation were indexed using HR (beats per minute) and SCL. HR was measured using electrocardiography (ECG) with disposable adhesive Ag/AgCl electrodes placed below the right clavicle and lower left ribcage, referenced to the left clavicle, and amplified via an ML138 Octal Bio Amp. SCL was recorded using bipolar dry stainless steel electrodes (MLT116F) attached to the medial phalange of the index and ring fingers of the participants' left hand and amplified using an ML116 AC amplifier. HR and SCL were converted from analog to digital signals at 1 kHz, using ADInstrument's Powerlab 16/30, and recorded in LabChart (Version 8.0.1). For a second set of measures, we simultaneously recorded HR and skin conductance via an E4 wristband (Empatica Inc, 2019) worn on the left wrist.[1]

Emotion and Presence Ratings. Participants provided verbal ratings at five distinct time-windows. At each time-window, the experimenter verbally asked participants to provide ratings on a 10-point scale, to describe the extent to which they were currently experiencing the six emotions of interest (i.e., fear, anxiety, relaxation, happiness, anger, and sadness). The scale ranged from 1 meaning that they were *not feeling that emotion at all* and 10 meaning their experience of that *emotion was extremely intense*. The order in which emotions were assessed was randomized for each time-window, and the experimenter entered their response in real-time on a smartphone via Qualtrics (https://www.qualtrics.com). Participants also rated their subjective presence during these same five time-windows. Presence was defined for participants as follows: "By presence, we mean how much you feel as if you are actually inside the virtual world, not how much you think the virtual world is like the real world." Participants responded verbally to the presence item on the same 10-point scale with endpoints 1 (*did not feel present at all*) and 10 (*feeling extremely present*).

Questionnaires. All questionnaires were presented using Qualtrics (https://www.qualtrics.com). These questionnaires included: the Discrete Emotions Questionnaire (DEQ; Harmon-Jones et al., 2016), the Acrophobia Questionnaire (AQ; Cohen, 1977), the revised Presence Questionnaire (PQ; Witmer et al., 2005), the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003), the Immersive Tendencies Questionnaire (ITQ; Witmer & Singer, 1998), the Depression, Anxiety, and Stress Scale (DASS-21; Henry & Crawford, 2005), and the Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993). The DEQ was administered both before and after participants experienced the virtual reality simulation, allowing us to assess changes associated with the plank experience. The other questionnaires were used to probe relations between variables for exploratory purposes but are not the primary focus of this study. Therefore, further information about these questionnaires and descriptive statistics can be found in the online supplemental materials.

Procedure

Figure 1 shows a timeline of key events in the virtual reality scenario. Participants first completed the DEQ, as well as demographic questions about age and gender, on a computer outside virtual reality. An experimenter explained that the virtual reality scenario would involve walking along a plank. The physical plank was placed on the laboratory floor and participants were asked to remove their shoes and practice walking along it. Participants were asked to keep their shoes off for the remainder of the experiment so that they could feel the wooden plank beneath their feet. The experimenter instructed participants on how to attach their own ECG electrodes and the experimenter attached the SCL finger electrodes. Finally, participants were fitted with the virtual reality headset and held a Vive controller in their right hand.

Upon entering the simulation, participants were immersed in a city street environment and positioned on a footpath facing the street. The experimenter asked participants to begin walking toward the curb of the footpath, encouraging them to look around the virtual environment. Once participants reached the curb, the experimenter asked for their first set of emotion and presence ratings (curb). Participants were then instructed to turn around, walk back across the footpath, and enter an open elevator at the entrance of a high-rise building. Once inside the elevator, participants were asked to provide a second set of ratings (bottom). Participants were instructed to press a button labeled "Plank" by reaching forward using their controller, which caused the virtual elevator to rise. When the elevator doors opened, participants saw a wooden plank extending outward from the floor of the elevator, suspended 80 stories above the ground. Participants provided a third set of ratings (top) and were instructed to then step onto the plank.[2] Once participants had stepped onto the plank with both feet, the experimenter asked them to pause to complete a fourth set of ratings (start). Participants were then told that their task was to walk to the end of the plank. If participants were successful in reaching the end of the plank, the experimenter asked for their fifth set of ratings. If participants wished to stop partway through the plank walk but were willing to complete the final set of ratings before removing their headsets, ratings were collected at this point.

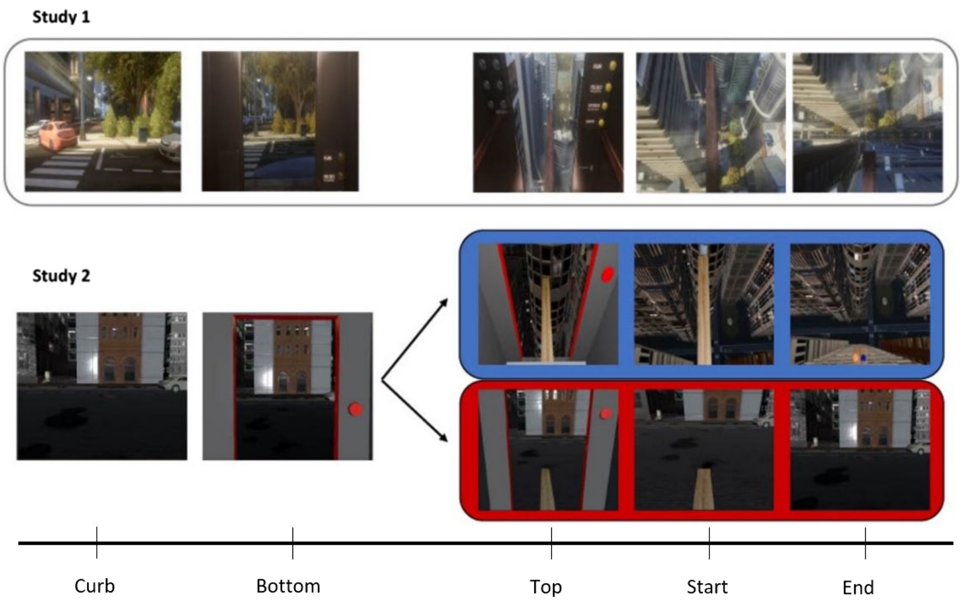
When participants reached the end of the plank, they were told that the virtual reality portion of the experiment was over. At this point, we offered them the choice of ending the experiment by stepping off the plank (in which case, they would experience a "falling"

[1] HR data collected via the E4 in Study 1 had lower absolute values than the ADInstrument device, producing HRs 10–15 bpm lower than expected. Without access to the proprietary Empatica algorithms that were used to calculate HR via photoplethysmography, we were not able to determine the cause of this discrepancy. As such, we only used the ADInstrument data in Study 1. After further piloting of the Empatica device before Study 2, we resolved this discrepancy, which was likely caused by poor device fit to participants' wrists, finding improved HR validity from the less invasive E4 device. We therefore used the E4 exclusively in Study 2.

[2] Note that the real wooden plank was aligned to the virtual plank by ensuring that the real plank was aligned to an outline shape taped on the laboratory floor. Because the virtual environment spatially calibrates to the position of the base stations, which were held constant throughout the study, the taped outline ensured that alignment was always accurate.

Figure 1

Images of Participants' Point of View During the Virtual Reality Simulation



Note. Verbal ratings were collected during five time-windows, labeled curb, bottom, top, start, and end. In Study 1 (top panel), we used Richie's Plank Experience (Toast, 2017). In Study 2 (bottom panel), a new simulation was developed to provide a matching control condition where the plank appears on the ground floor. The three images in the upper box depict the height condition, and the images in the lower box depict the control condition. See the online article for the color version of this figure.

simulation) or being teleported to the ground (in which case, the simulation would fade to black and participants would find themselves back where the virtual reality scenario began). Fifty-eight participants successfully reached the end of the plank. Thirteen (22.4%) chose to step off the plank and experience the falling simulation, and 45 chose to be teleported to the ground floor. Participants spent 3–5 min in virtual reality depending on how quickly they walked the plank and responded to verbal ratings. Following the virtual reality scenario, participants completed the DEQ, ERQ, SSQ, PQ, and ITQ, as well as questions about participants' previous experience with virtual reality. After completing the questionnaires, participants were fully debriefed, thanked for their participation, and dismissed.

Data Preparation and Exclusions

Six participants asked to stop the experiment before reaching the end of the plank. Three of these participants decided to complete their final set of ratings at their furthest point before removing the headset; these data are included in the analyses. One additional participant accidentally stepped off the plank before they reached the end, triggering the falling animation, and therefore did not complete the final ratings. Missing data for emotion ratings could not be imputed from previous responses because each set of ratings reflects a different time-point. In total, seven participants were excluded from analyses due to missing data resulting from recording failures or needing to end the experiment early without providing final ratings. Therefore, the final sample size is 58.

HR was measured in beats per minute, and SCL was measured in microsiemens. To capture sympathetic activation across the simulation, we extracted average values from five 10-s windows during which participants were stationary and completing verbal ratings. These stationary ratings periods were not affected by movement artifacts and provided physiological measures that corresponded to the concurrent emotion ratings. The ADInstuments system requires that SCL is subject-zeroed at the start of each session. Therefore, SCL readings reflect values relative to a participant's level at the start of the experiment, rather than absolute values. Importantly, the ADInstuments system can record SCL ranging from -40 to $+40$ μS relative to the subject zero. Maximum SCL readings were reached during 35 time-windows (10.7% of the 325 time-windows) across 17 participants. These samples were recorded as 40 μS. Due to this measurement limitation, the SCL results reported here represent a conservative estimate of the effect. SCL data were transformed by taking the log(μS + 1) (Boucsein et al., 2012).

All time-windows were manually inspected for artifacts. Artifacts were defined as rapid deflections in the ECG and/or SCL waveforms that could not be accounted for by normative changes in the autonomic nervous system, and could only be accounted for by external factors (e.g., physiological body actions like coughing, movements, or errors in the recording system). Samples containing artifacts were excluded from the time-window. However, if more than one third of the samples in a time-window contained artifacts, the entire time-window was excluded from the analysis. In such cases, we set the time-window to begin immediately following the artifact in the data and continued for 10 s. The application of these criteria resulted in the offsetting of three HR time-windows and three SCL time-windows. In one case, the offsetting of the time-window caused an overlap with the beginning of the next window. Therefore, that window was truncated.

Analysis Plan

The following analyses examine the impact of height exposure on subjective and physiological changes consistent with fear. If height exposure successfully induces a fear response, we predict that self-reported fear and anxiety would increase during height exposure, relative to baseline ratings collected before they entered the elevator. We also predict that self-reported happiness and relaxation will decrease at height as compared to baseline. Because we predict that height exposure is related to fear rather than a generalized negative affect, we expected no differences as a function of height for self-ratings of sadness or anger. Furthermore, we predicted that HR and SCL would be increased during height exposure, relative to baseline levels. It was also expected that self-reported ratings of presence will be greater at height compared to baseline presence. To test these predictions, we first conducted one-way analyses of variance (ANOVAs) with time as a within-subjects factor with five levels (curb, bottom, top, start, and end) to assess changes in emotion ratings, HR, SCL, and presence.

Because exposure to height occurred after the bottom time-window and immediately before the top time-window, we predicted that ratings, HR, and SCL would change between these two time-windows, specifically. To test this prediction, we followed up significant results in the one-way ANOVAs with planned comparisons using one-tailed paired-samples t tests comparing bottom and top time-windows. We reason that if these predictions are confirmed, this would justify the creation of two meaningfully distinct conditions within the virtual reality scenario. Because the first two time-windows (curb, bottom) occur before the height exposure, data corresponding to these two windows were averaged to create measures of subjective emotion, HR, and skin conductance at baseline level, and the final three time-windows (top, start, end) were averaged to create measures at plank level. Using these baseline and plank time-windows, we conducted paired-samples t tests to test the predictions that fear, anxiety, and presence ratings (along with HR and SCL) were increased at plank relative to baseline, while ratings of relaxation and happiness decreased.

A second set of analyses examined the hypothesis that changes in subjective fear and/or sympathetic activation predict presence. A hierarchical multiple regression was conducted in which we first controlled for baseline ratings of presence (i.e., self-reported presence before exposure to height), and then examined the extent to which changes in subjective fear, HR, and skin conductance predicted presence on the plank. All data analyses were performed using RStudio Version 2022.07.1. Effect sizes are reported as partial eta squared for ANOVAs, Cohen's d_z are computed for comparison of means within-subjects, and Cohen's d_s are computed for comparisons of means between-subjects (Lakens, 2013). Greenhouse–Geisser corrections were applied when the assumption of sphericity was violated.

Transparency and Openness Statement

We describe our sampling plan, all data exclusions, all manipulations, and all measures in the study. We have made all data, analysis code, and research materials available at https://osf.io/6s3mf/. Study 1 was not preregistered.

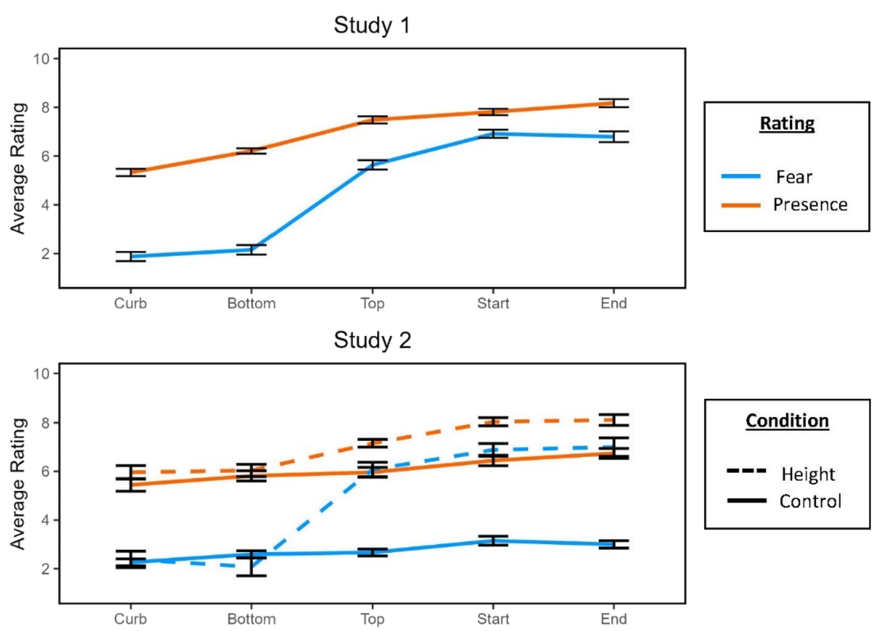
Results and Discussion

Emotions and Presence Ratings

Figure 2 (top panel) shows how fear and presence ratings changed over the course of the five time-windows. Separate repeated measures one-way ANOVAs were used to test whether emotion ratings changed over time. Significant effects were found for ratings of all emotions, as well as presence (see Table 1 for mean ratings

Figure 2

Changes in Fear and Presence Ratings Across Five Time-Windows



Note. See the online article for the color version of this figure.

Table 1
Summary Statistics and ANOVA Results for Emotion Ratings and Presence, as Well as HR and SCL Across Five Time-Windows

	M (*SD*)					One-way ANOVA results		
Emotion	Curb	Bottom	Top	Start	End	*F*	*p*	η_p^2
Presence	5.3 (1.8)	6.2 (1.6)	7.5 (1.7)	7.8 (1.8)	8.2 (2.0)	71.27	<.001	.56
Fear	1.9 (1.4)	2.2 (1.6)	5.6 (2.5)	6.9 (2.4)	6.8 (2.7)	163.08	<.001	.74
Anxiety	2.7 (2.0)	2.8 (2.1)	6.0 (2.4)	7.0 (2.4)	7.1 (2.5)	145.98	<.001	.72
Relaxation	5.3 (2.1)	5.1 (2.2)	3.0 (1.8)	2.6 (2.0)	2.3 (1.4)	53.19	<.001	.48
Happiness	6.5 (1.7)	6.3 (1.7)	4.7 (2.2)	4.3 (2.2)	4.3 (2.4)	37.57	<.001	.40
Anger	1.2 (0.7)	1.2 (0.5)	1.5 (1.0)	1.6 (1.1)	1.6 (1.2)	8.07	<.001	.12
Sadness	1.3 (0.7)	1.3 (0.6)	1.4 (0.8)	1.7 (1.1)	1.9 (1.6)	8.96	<.001	.14
HR	95.2 (8.4)	93.1 (8.0)	99.4 (5.9)	110.8 (9.7)	108.5 (10.2)	49.16	<.001	.46
SCL	2.8 (0.2)	2.8 (0.2)	3.0 (0.1)	3.2 (0.1)	3.3 (0.2)	125.23	<.001	.69

Note. ANOVA = analysis of variance; HR = heart rate; SCL = skin conductance level.

and ANOVA results). Planned comparisons were conducted to test the prediction that significant changes would occur specifically between the bottom and top time-windows. As predicted, ratings significantly increased for fear, $t(57) = 11.75$, $p < .001$, $d_z = 1.54$; anxiety, $t(57) = 11.97$, $p < .001$, $d_z = 1.57$; and presence, $t(57) = 7.75$, $p < .001$, $d_z = 1.02$, whereas ratings significantly decreased for relaxation, $t(57) = -7.37$, $p < .001$, $d_z = 0.97$, and happiness $t(57) = -8.52$, $p < .001$, $d_z = 1.12$. Anger ratings also increased, $t(57) = 3.04$, $p = .004$, $d_z = 0.39$; however, this effect was much smaller relative to the other effects. Sadness ratings did not significantly differ between these two time-windows, $t(57) = 1.26$, $p = .21$, $d_z = 0.17$.

These changes validate the use of the elevator to separate the procedure into two meaningfully distinct time-windows. Therefore, we calculated new rating values by averaging the ratings collected before height exposure (i.e., curb and bottom time-windows) to represent participants' emotion ratings at baseline, and averaging the ratings collected during height exposure (i.e., top, start, and end time-windows) to represent participants' emotion ratings at plank level. These new ratings were compared using paired-samples *t* tests. Results showed that ratings of fear, anxiety, presence, anger, and sadness were increased at plank level relative to baseline, while ratings of relaxation and happiness decreased (see Table 2). Taken together, these results provide validation that the virtual reality scenario functions as a powerful manipulation of emotional state, producing subjective responses consistent with fear.

Table 2
Summary Statistics and Test Statistics for Average Ratings, as Well as HR and SCL at Baseline and Plank Levels

	Baseline	Plank			
Emotion	*M* (*SD*)	*M* (*SD*)	*t*(57)	*p*	Cohen's d_z
Presence	5.8 (1.8)	7.8 (1.8)	12.77	<.001	1.68
Fear	2.0 (1.5)	6.5 (2.6)	16.62	<.001	2.18
Anxiety	2.7 (2.1)	6.7 (2.5)	16.27	<.001	2.14
Relaxation	5.2 (2.2)	2.7 (1.8)	−9.52	<.001	1.25
Happiness	6.4 (1.7)	4.5 (2.3)	−8.82	<.001	1.16
Anger	1.2 (0.6)	1.6 (1.1)	3.50	.001	0.46
Sadness	1.3 (0.7)	1.7 (1.2)	3.30	.002	0.43
HR	94.2 (15.3)	106.2 (18.6)	8.44	<.001	1.11
SCL	2.8 (0.5)	3.2 (0.4)	13.48	<.001	1.77

Note. HR = heart rate; SCL = skin conductance level.

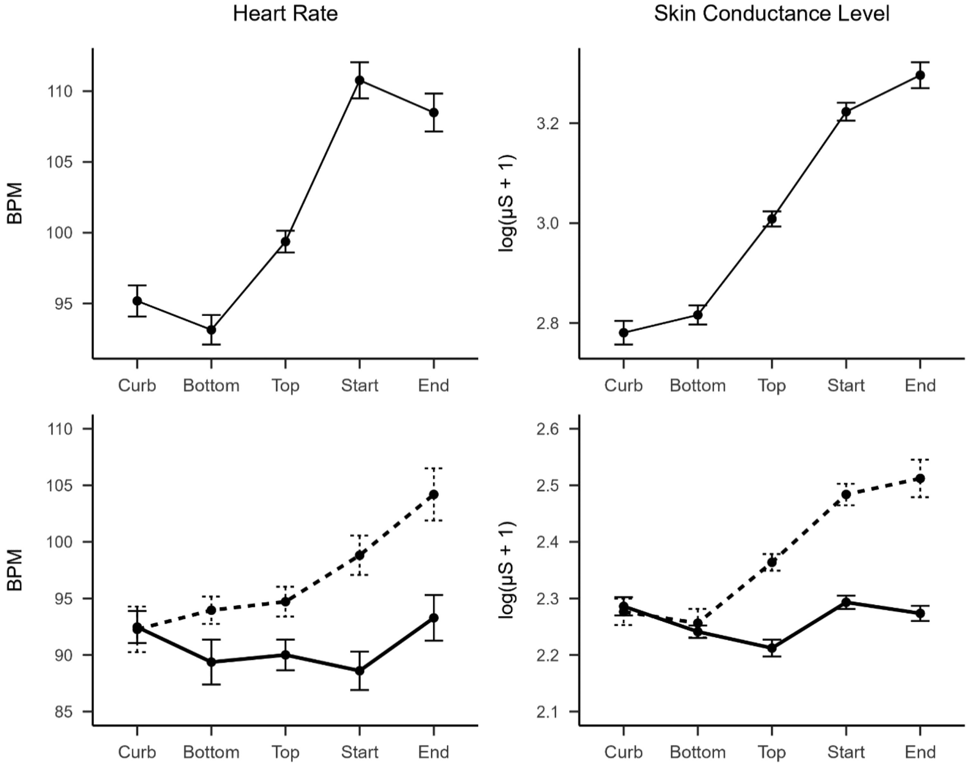
Physiological Measures

HR and SCL were submitted to the same analyses as the ratings. One-way repeated measures ANOVAs revealed a significant effect of time on HR, $F(4, 228) = 49.16$, $p < .001$, $\eta_p^2 = .46$, and SCL, $F(4, 228) = 125.23$, $p < .001$, $\eta_p^2 = .69$. See Figure 3 for a depiction of the effect. Means and standard deviations are reported in Table 1. Follow-up planned comparisons comparing bottom to top time-windows revealed significant increases in HR, $t(57) = 6.53$, $p < .001$, $d_z = 0.86$, and SCL, $t(57) = 8.46$, $p < .001$, $d_z = 1.11$. Finally, paired-samples *t* tests confirmed that sympathetic activation was significantly increased at plank level relative to baseline, HR, $t(57) = 8.44$, $p < .001$, $d_z = 1.11$, and SCL, $t(57) = 13.48$, $p < .001$, $d_z = 1.77$. These results further validate the use of the virtual reality scenario to manipulate emotional state, producing responses consistent with fear across both subjective and physiological components of emotion.

Relationships Between Presence, Fear, and Sympathetic Activation

To determine the extent to which changes in subjective and physiological components of fear (from baseline to plank) predict presence, we conducted a hierarchical multiple regression. The data were examined to ensure that all assumptions were met for running multiple regressions. As a shorthand for changes (from baseline to plank) in fear ratings, or HR, or SCL, these change variables will be hereafter denoted as Δfear, ΔHR, and ΔSCL, respectively. Table 3 presents a correlation matrix of all variables in the model; note that ΔHR and ΔSCL were positively correlated with each other, $r(56) = .47$, $p < .001$, and both were positively correlated with Δfear, $r(56) = .34$, $p = .01$ for ΔHR and $r(56) = .31$, $p = .017$ for ΔSCL, suggesting some coherence across subjective and physiological systems. In Step 1, presence at baseline was entered into the model as the single predictor of presence on the plank. This allowed us to control for individual differences in presence within virtual reality. The model significantly predicted presence on the plank, $F(1, 56) = 57.65$, $p < .001$, adjusted $R^2 = .50$. In Step 2, the addition of Δfear, ΔHR, and ΔSCL collectively accounted for an additional 11.6% of the variance in presence on the plank, beyond that accounted for by presence at baseline, adjusted $R^2 = .59$. Next, we calculated the semipartial correlation between Δfear and presence on the plank, controlling for presence at baseline, $r(56) = .48$, $p < .001$. The significant

Figure 3
Changes in Heart Rate and Skin Conductance Level Across Five Time-Windows



Note. Mean heart rate (in BPM; left panels) and skin conductance (log(µS + 1); right panels) across time. The top row corresponds to Study 1 data and the bottom row corresponds to Study 2, where data from the control condition are depicted with solid lines and the data from the height condition are depicted with dashed lines. Error bars are within-subjects standard errors. BPM = beats per minute.

relationship indicates that Δfear uniquely explained a significant proportion of the variance in presence on the plank, beyond that accounted for by presence at baseline. However, neither ΔHR nor ΔSCL predicted presence on the plank. See Table 4 for model-specific coefficients.

In summary, Study 1 confirmed that the virtual reality plank walk was associated with strong subjective and physiological changes consistent with fear, consistent with a body of research showing effective emotional induction in virtual reality (Andreatta et al., 2023; Gromer et al., 2019). The pattern of changes observed in the emotion ratings and physiological measures are consistent with fear, evidenced by increased HR, SCL, fear and anxiety ratings, and decreased happiness and relaxation ratings. Although we were surprised to find that ratings of anger and sadness significantly increased when participants were at height, the magnitude of those effects was considerably smaller than for the other emotions. Therefore, we interpret this pattern of results as evidence that height exposure in virtual reality is associated with a specific fear response, as well as an overall negative and high-arousal emotional experience. We also replicated the positive relationship between self-reported fear and presence while participants were at height (Gromer et al, 2019). Contrary to interoceptive accounts

Table 3
Descriptive Statistics and Correlations for Study Variables

Variable	*M*	*SD*	1	2	3	4	5
1. Plank presence	7.8	1.6	—				
2. Baseline presence	5.8	1.6	.70**	—			
3. ΔFear	4.4	2.0	.51**	.24	—		
4. ΔHR	12.1	10.9	.06	−.02	.34*	—	
5. ΔSCL	0.4	0.2	.15	.14	.31*	.47**	—

Note. HR = heart rate; SCL = skin conductance level.
* $p < .05$. ** $p < .01$.

Table 4
Multiple Regressions: Predicting Presence on the Plank

Effect	Estimate	*SE*	95% CI LL	95% CI UL	*p*
Fixed effects					
Intercept					<.001
Baseline presence	0.71	0.09	0.52	0.90	<.001
Intercept					<.001
Baseline presence	0.62	0.09	0.47	0.81	<.001
ΔFear	0.37	0.09	0.18	0.55	<.001
ΔHR	−0.01	0.10	−0.20	0.19	.920
ΔSCL	−0.08	0.10	−0.27	0.12	.420

Note. Estimates represent standardized regression weights. CI = confidence interval; LL = lower limit; UL = upper limit; HR = heart rate; SCL = skin conductance level.

(Diemer et al., 2015; Seth et al., 2012), the increase in presence was predicted by subjective fear, but not by sympathetic activation.

Of course, these associations do not give us a license to make causal inferences. All participants completed the plank walk after the baseline measures, and the simulation introduced a number of immersive features that could have enhanced presence (e.g., being able to control the elevator, feeling the physical plank underfoot). Therefore, in Study 2 we introduced a control condition that included the same features of the plank walk, but without the fear-inducing height exposure.

Study 2

In Study 2, we replicated the procedure of Study 1, but participants were randomly assigned to walk the plank at height, or to a control condition in which they still traveled in the elevator and walked the plank, but the plank was placed on the ground floor in the simulation. The control condition allowed us to determine whether changes in subjective, physiological, and behavioral responses could be attributed to heights, or to other aspects of the plank walk. We expected that participants would show increases in subjective and physiological measures in the height condition, that exceeded any observed in the control condition. We also recorded walking speed on the plank for a subset of our participants, which were further used to determine whether the simulation induced behavioral changes consistent with fear. Finally, we tested whether the effect of height on presence is mediated by changes in subjective fear or sympathetic activation.

Method

Participants

Sixty (46 female, 14 male, zero nonbinary) undergraduate psychology students from Victoria University of Wellington, ages 17–34 years ($M = 18.9$, $SD = 2.3$) were randomly assigned to either the height or control condition. None of the participants had participated in Study 1. Demographic information was obtained using the same questionnaire as in Study 1. As in Study 1, we did not collect information about participants' ethnicity. Following the application of all exclusion criteria, the final sample size submitted for analyses, was 53, with 27 participants in the control condition and 26 in the height condition. G*Power estimates that this sample size gives us 90% power to detect a small-to-medium interaction ($\eta_p^2 = .04$) between time-window and condition, the primary test of the hypothesis that height exposure causes fear. The same exclusion criteria were used as in Study 1. Participants provided written informed consent before taking part.

Materials and Apparatus

Virtual Reality Simulation. We created a new simulation that was modeled on the commercial simulation used in Study 1 so that we could manipulate the height of the plank. The new simulation was built in Unity (Version 2018.3.5f1). As in Study 1, participants used an HTC Vive controller in their right hand to press the elevator button. A different room was used to conduct Study 2; the new space was 4.6 m × 2.7 m. The base stations were fastened to opposite corners of the rectangular room, at a height of 2.5 m, and were 4.9 m apart. Finally, we introduced an HTC Vive wireless adapter to the headset allowing the headset to connect to the desktop computer wirelessly.

Physiological Measures. HR, indexed as beats per minute, and SCL, in microsiemens, were recorded continuously throughout the virtual reality simulation, using an Empatica E4 wristband secured to participants' left wrist. HR was derived from the blood volume pulse, measured using a photoplethysmography sensor sampled at 64 Hz. SCL was measured using 1″ electrodes with isotonic recording gel adhered to the thenar and hypothenar regions of participants' left hand, sampled at 4 Hz. The wireless E4 device was used, instead of the wired ADInstruments system used in Study 1, because it is more comfortable for participants and results in fewer movement-related artifacts.

Behavioral Data. Participant motion was recorded using the third-party software Brekel OpenVR Recorder (Brekelmans, 2019). This software tracked the position of the HTC Vive headset, hand controller, and two HTC Vive trackers which were attached to the top of participants' feet using elastic bands. Importantly, this software also recorded audio using the microphone inside the HTC Vive headset.

Procedure

Overall, the procedure for Study 2 closely matched Study 1, with the addition of the control condition (see Figure 1), in which the elevator rose halfway, then returned to the ground floor before the doors opened, revealing a wooden plank extending from the entrance of the elevator and resting on the street. In the height condition, the elevator doors opened at approximately 80 stories above the city street, as in Study 1. Participants verbally provided presence and emotion ratings at the same five time-windows as in Study 1 (i.e., curb, bottom, top, start, and end). Unlike Study 1, participants in Study 2 were asked to attach two HTC Vive trackers to their feet using elastic bands. In the virtual environment, participants could see where their feet were located, represented as colored cubes. The rationale for adding these trackers is to provide participants with a more accurate sense of where their feet are in the virtual environment, to help participants balance on the plank, and so that we could track the movement of their feet during the plank walk.

As in Experiment 1, participants in the height condition were told that the virtual reality portion of the study was complete, and given the option to either step off the plank and experience a falling simulation back to the ground floor or to end the simulation by removing the headset. Twelve participants (out of 28; 42.9%) chose to step off the plank and fall. Participants in the control condition were informed they had reached the end of the simulation when they had completed their final set of ratings at the end of the plank. Participants then completed the same questionnaires from Study 1 with the addition of the I-Group Presence Questionnaire (IPQ, Schubert et al., 2001), and excluding the ITQ and the DASS-21 (see the online supplemental materials for descriptive statistics from all questionnaires).

Data Preparation and Exclusions

Two participants in the height condition asked to stop the experiment before reaching the end of the plank. Both of these participants chose not to complete final ratings, and therefore their data are not included in the analyses. Physiological data were not collected for five additional participants due to recording errors; data from those participants were also excluded from analyses. Following these exclusions, the total sample size submitted for analyses was 53, with 27 participants in the control condition and 26 in the height condition. HR and SCL time-windows were the same duration as in Study 1. Artifact removal followed the same procedure as in Study 1. One time-window was adjusted to remove one second of SCL data which contained movement artifacts. No artifacts were found in the HR data.

For the exploratory analysis of movement, positional tracking data were processed using Autodesk MotionBuilder (https://www.autodesk.com/products/motionbuilder/). To calculate the latency to step onto the plank, a human coder played the file and listened to the audio for the moment when the experimenter finished instructing the participant to step onto the plank with both feet. This moment was recorded as the "start" frame. The coder then scrolled forward through the file until the moment when both of the participant's Vive trackers had moved onto the plank. This moment was recorded as the "end" frame. Finally, the latency to step onto the plank was calculated by subtracting the "end" frame from the "start" frame, and this number was converted to seconds by dividing by 60. To calculate the time to complete the plank walk, a human coder scrolled forward through the file until they identified the first step that the participant took after stepping onto the plank with both feet. The first frame where it could be determined that one of the trackers had initiated a step was recorded as the "start of walk" frame. The coder then scrolled forward through the file until they could identify the frame when the participant completed the last step before providing the final set of verbal ratings. This frame was recorded as the "end of walk" frame. The time to complete the plank walk measure was calculated by subtracting the "end of walk" frame from the "start of walk" frame, and this number was then converted to seconds by dividing by 60. Seven participants' motion data were either not recorded due to experimenter error or the recording quality was too poor to identify critical time points for both measures. In addition, motion data for 14 additional participants were unable to be used to calculate latency to step onto the plank due to poor data quality occurring in the first half of the recording, and one additional participant's data were unable to be used to calculate time to complete the plank walk due to poor data quality occurring in the latter half of the recording. Therefore, for latency to step onto the plank, a total of 40 participants' motion data were submitted for analysis (height condition $n = 20$, control condition $n = 20$) and for time to complete the plank walk, a total of 53 participants' motion data were submitted for analysis (height condition $n = 25$, control condition $n = 28$).

Analysis Plan

The preregistered analyses focus on comparisons between baseline (i.e., average of curb and bottom time-windows) and plank (i.e., average of top, start, and end time-windows). In the following sections, we also present exploratory analyses in which all five time-windows are retained, providing greater granularity for exploring changes in fear and presence over time. We refer to the former (preregistered) analyses as confirmatory and the latter as exploratory.

Factorial mixed-methods ANOVAs with condition (control vs. height) as a between-subjects factor and time as a within-subjects factor were used to examine the impact of height exposure on subjective and physiological components of fear. Based on the findings of Study 1, we expect height exposure to produce a fear response as indicated by significant Condition × Time interactions. That is, it was expected that the differences between these components of fear as a function of time (i.e., baseline vs. plank) would be greater for participants who were in the height condition than for participants who walked the plank on the ground floor (i.e., control condition). As an additional exploratory prediction, we also expected that participants in the height condition would be more hesitant to step onto the plank relative to controls and that participants in the height condition would take longer to walk the plank relative to controls. To test these predictions, we planned to conduct one-tailed independent-sample t tests to compare latency to step onto the plank and time to complete the plank walk between conditions.

Following these analyses, we used a mediational modeling approach to evaluate whether subjective and/or physiological components of the fear response may be underlying the relationship between exposure to height and feelings of presence. We first calculated change scores (plank—baseline) for self-reported fear, HR, and SCL, and used simple mediation models (Hayes', 2018, PROCESS Macro (Model 4) with 10,000 bootstrapped samples) to determine which, if any, of these predictors mediated the relationship between condition (i.e., height exposure) and presence. Finally, we repeated the hierarchical regression from Study 1 in just the participants who walked the plank at height, to determine whether the relationship between fear measures and presence replicated.

Transparency and Openness Statement

We describe our sampling plan, all data exclusions, all manipulations, and all measures in the study. We have made all data, analysis code, and research materials available at the Open Science Framework (see Maymon et al., 2023). The design and analysis of Study 2 were preregistered at https://osf.io/embzr.

Results and Discussion

Emotions and Presence Ratings

Figure 2 (bottom panel) shows how fear and presence ratings changed over the course of the five time-windows. Means and standard deviations by condition and time-window are shown in Table 5. Separate 2 (condition: height vs. control) × 5 (time: curb, bottom, top, start, end) factorial mixed models ANOVAs were run for each emotion, as well as presence, to test for predicted Time × Condition interactions. The analyses revealed significant interaction effects for ratings of fear, $F(2.82, 143.77) = 36.04$, $p < .001$, $\eta^2_p = .41$; anxiety, $F(2.56, 130.73) = 32.74$, $p < .001$, $\eta^2_p = .39$; relaxation, $F(3.15, 160.89) = 19.96$, $p < .001$, $\eta^2_p = .28$; happiness, $F(2.71, 138.35) = 18.27$, $p < .001$, $\eta^2_p = .26$; sadness, $F(1.85, 94.40) = 3.49$, $p = .038$, $\eta^2_p = .06$; and presence, $F(2.37, 120.84) = 3.54$, $p = .025$, $\eta^2_p = .06$. Consistent with Study 1, participants in the height condition showed large increases over time in fear, $F(2.50, 62.51) = 55.00$, $p < .001$, $\eta^2_p = .69$; anxiety, $F(2.33, 58.13) = 65.80$, $p < .001$, $\eta^2_p = .73$; and presence, $F(2.04, 50.98) = 22.2$, $p < .001$, $\eta^2_p = .47$, and large decreases in relaxation, $F(2.61, 65.27) = 39.30$, $p < .001$, $\eta^2_p = .61$, and happiness, $F(2.61, 65.22) = 25.00$, $p < .001$, $\eta^2_p = .50$, and a relatively smaller increase in sadness, $F(1.73, 43.20) = 3.5$, $p = .045$, $\eta^2_p = .12$. Participants in the control condition showed significant but much smaller increases in fear, $F(2.53, 65.91) = 5.15$, $p = .005$, $\eta^2_p = .17$; anxiety, $F(2.67, 69.37) = 3.74$, $p = .018$, $\eta^2_p = .13$; and presence, $F(2.63, 68.45) = 5.56$, $p = .003$, $\eta^2_p = .18$, and no change

Table 5
Summary Statistics for Subjective Emotion Ratings and Presence in Study 2

		Time-window				
Condition	Rating	Curb	Bottom	Top	Start	End
Control	Presence	5.4 (1.6)	5.8 (1.7)	6.0 (2.0)	6.4 (2.0)	6.7 (1.9)
	Fear	2.3 (1.3)	2.6 (1.7)	2.7 (1.5)	3.2 (1.8)	3.0 (2.0)
	Anxiety	3.0 (1.8)	3.0 (1.7)	3.3 (1.8)	3.7 (2.1)	3.7 (2.1)
	Happiness	6.8 (1.8)	6.6 (2.0)	6.7 (2.0)	6.4 (2.0)	6.6 (2.1)
	Relaxation	4.8 (2.3)	5.5 (2.1)	5.5 (2.2)	4.9 (1.8)	5.0 (2.1)
	Anger	1.2 (0.7)	1.2 (0.5)	1.2 (0.7)	1.2 (0.6)	1.3 (1.0)
	Sadness	1.5 (1.2)	1.6 (1.3)	1.5 (1.2)	1.6 (1.4)	1.5 (1.3)
Height	Presence	6.0 (1.8)	6.0 (2.2)	7.2 (2.1)	8.0 (2.0)	8.1 (1.9)
	Fear	2.4 (1.6)	2.1 (1.5)	6.1 (2.6)	6.9 (2.4)	7.0 (2.6)
	Anxiety	2.8 (1.8)	2.6 (1.8)	6.3 (2.6)	7.3 (2.0)	7.4 (1.9)
	Happiness	6.4 (1.3)	6.5 (1.2)	4.7 (1.9)	4.3 (1.8)	4.1 (2.0)
	Relaxation	5.0 (1.7)	5.2 (2.0)	2.7 (1.8)	1.9 (1.2)	2.4 (1.9)
	Anger	1.1 (0.4)	1.2 (0.4)	1.3 (0.7)	1.6 (1.4)	1.4 (1.2)
	Sadness	1.2 (0.5)	1.2 (0.5)	1.6 (0.9)	1.9 (1.3)	2.0 (2.2)

Note. The table presents mean ratings, with standard deviations in brackets. These values reflect a total $N = 53$ ($n = 27$ in the control condition and $n = 26$ in the height condition). Ratings were collected using a range of 1–10, across five time-windows.

in relaxation, $F(2.83, 73.53) = 2.16$, $p = .104$, $\eta_p^2 = .08$; happiness, $F(2.76, 71.72) = 1.55$, $p = .211$, $\eta_p^2 = .06$; or sadness, $F(1.75, 45.57) = 0.47$, $p = .602$, $\eta_p^2 = .02$. These ratings largely mirror those in Study 1 apart from the small effect of height on anger that did not replicate. This similar pattern of results suggests that our new simulation in Study 2 effectively reproduced the height experience in the original game.

For the preregistered confirmatory analysis, we predicted significant Condition × Time interactions, such that ratings of fear and presence would increase at plank, relative to baseline, in the height condition only. Results confirmed these predictions, revealing a significant Condition × Time interaction for ratings of fear, $F(1, 51) = 71.19$, $p < .001$, $\eta_p^2 = .58$, and presence, $F(1, 51) = 5.66$, $p = .021$, $\eta_p^2 = .10$. Follow-up paired-samples t tests examining the effect of time in each condition showed large increases in fear in the height condition, $t(25) = 9.88$, $p < .001$, $d_z = 1.94$, and significant but smaller increases in fear in the control condition, $t(26) = 3.53$, $p = .001$, $d_z = 0.68$. There were also large increases in presence in the height condition, $t(25) = 5.53$, $p < .001$, $d_z = 1.08$, and significant yet smaller increases in presence in the control condition, $t(26) = 2.65$, $p = .013$, $d_z = 0.51$. Taken together, this pattern of results shows that height exposure increased both fear and presence over and above the smaller increases associated with walking the plank seen in the control condition.

Physiological Responses

Figure 3 depicts the changes in physiological measures across the five time-windows in the control and height conditions. Measures of sympathetic activation (HR and SCL) were analyzed in the same way as the emotion ratings. For SCL, the exploratory 2 (condition: height vs. control) × 5 (time: curb, bottom, top, start, end) mixed-measures ANOVA revealed a significant main effect of time, $F(1.68, 85.77) = 23.64$, $p < .001$, $\eta_p^2 = .32$ which was subsumed by the significant Condition × Time interaction, $F(1.68, 85.77) = 16.06$, $p < .001$, $\eta_p^2 = .24$. The same pattern was observed in the HR data: a significant main effect of time, $F(2.63, 134.06) = 5.46$, $p = .002$, $\eta_p^2 = .10$ qualified by the significant Condition × Time interaction, $F(2.63, 134.06) = 3.47$, $p = .023$, $\eta_p^2 = .06$. Unpacking these interaction effects, in the height condition we observed large increases in HR, $F(2.53, 63.19) = 7.36$, $p < .001$, $\eta_p^2 = .23$, and SCL, $F(1.35, 33.63) = 23.80$, $p < .001$, $\eta_p^2 = .49$, whereas in the control condition, we observed no change in HR, $F(2.39, 62.23) = 1.39$, $p = .255$, $\eta_p^2 = .05$, and only a small increase in SCL, $F(2.78, 72.41) = 6.19$, $p = .001$, $\eta_p^2 = .19$.

Next, we turn to the preregistered confirmatory analysis using the baseline and plank averaged time-windows. Separate 2 (condition: height vs. control) × 2 (time: baseline, plank) mixed models ANOVAs revealed significant interactions for both HR, $F(1, 51) = 4.44$, $p = .040$, $\eta_p^2 = .08$, and SCL, $F(1, 51) = 24.31$, $p < .001$, $\eta_p^2 = .32$. Follow-up paired-samples t tests showed that HR increased as a function of time for the height condition, $t(25) = 2.92$, $p = .004$, $d_z = 0.57$, but not for the control condition, $t(26) = 0.13$, $p = .552$, $d_z = 0.03$. Similarly, SCL increased as a function of time in the height condition, $t(25) = 5.27$, $p < .001$, $d_z = 1.03$, but not for controls, $t(26) = 0.24$, $p = .593$, $d_z = 0.05$. Sympathetic activation at height can therefore be attributed to the fear response, and not to other aspects of the experience.

Behavioral Responses

For the latency to step onto the plank and time to complete the plank-walk measures, the data were found to be nonnormal. Therefore, one-tailed Mann–Whitney U tests were used. Results confirmed both predictions: latency to step onto the plank was significantly greater in the height condition ($Mdn = 5.3$, IQR = 4.2) relative to controls ($Mdn = 3.2$, IQR = 1.1), $U = 87.0$, $p = .001$; and participants took significantly longer to complete the plank walk in the height condition ($Mdn = 11.1$, IQR = 7.5) relative to controls ($Mdn = 5.4$, IQR = 1.9), $U = 97.5$, $p < .001$.

Relationships Between Presence, Fear, and Sympathetic Activation

Next, we used a mediational approach to determine whether changes to subjective fear and/or sympathetic activation mediated the relationship between height exposure and presence on the plank. As in Study 1, we calculated Spearman's rank correlations among presence, and the increases in subjective fear and sympathetic activation (see Table 6). Correlations in the height condition largely replicated those in Study 1. ΔFear correlated positively with presence on the plank while ΔHR and ΔSCL did not. ΔHR and ΔSCL correlated positively, showing coherence across these physiological measures. However, we did not replicate coherence across response systems, as physiological changes did not correlate with Δfear. In the control condition, only presence at baseline correlated with presence on the plank; no other significant correlations were observed.

Three simple mediation models (with Δfear, ΔHR, and ΔSCL as mediators, respectively) were then conducted to explain the relationship between the experimental condition (height exposure) and presence ratings while on the plank. We used Hayes' (2018) PROCESS Macro (Model 4). Bootstrapped confidence intervals were calculated with 10,000 samples. In the first mediation, tests revealed a significant total effect of height exposure on presence on the plank, $B = 1.39$, 95% CI [0.36, 2.41], $t(51) = 2.72$, $p = .009$. The mediator

Table 6

Descriptive Statistics and Correlations for Study Variables in the Height Condition (n = 26) and Control Condition (n = 27)

Condition	Variable	*M*	*SD*	1	2	3	4	5
Height	1. Baseline presence	6.0	1.9	—				
	2. Plank presence	7.8	1.9	.59**	—			
	3. ΔFear	4.4	2.3	.22	.52**	—		
	4. ΔHR	6.1	10.7	−.12	−.16	.09	—	
	5. ΔSCL	0.2	0.2	−.23	−.1	.04	.42*	—
Control	1. Baseline presence	5.6	1.5	—				
	2. Plank presence	6.4	1.8	.58**	—			
	3. ΔFear	0.5	0.8	.18	.14	—		
	4. ΔHR	−0.3	11.4	−.07	.01	−.15	—	
	5. ΔSCL	−0.0	0.1	−.14	−.35	−.01	−.1	—

Note. HR = heart rate; SCL = skin conductance level.
* $p < .05$. ** $p < .01$.

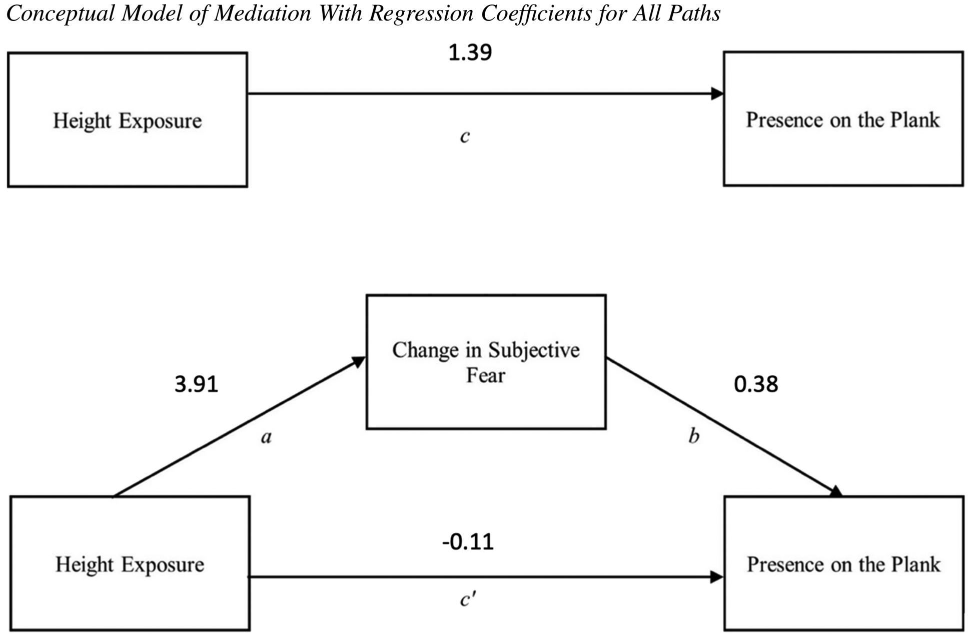
variable (Δfear) was significantly related to height exposure, $B = 3.91$, 95% CI [2.98, 4.84], $t(51) = 8.44$, $p < .001$, and to presence ratings on the plank, while accounting for the effect of height exposure, $B = 0.38$, 95% CI [0.09, 0.67], $t(50) = 2.62$, $p = .012$. Accounting for Δfear, the relationship between height exposure and presence ratings was no longer significant, $B = -0.11$, 95% CI [−1.61, 1.4], $t(50) < 1.0$, $p = .89$, indicating that the relationship between height exposure and presence on the plank was fully mediated by Δfear. Importantly, the PROCESS Macro can test for interaction effects between the antecedent and mediator variables; no interaction was found, $F(1, 49) = 0.02$, $p = .90$. Figure 4 shows the regression coefficients for all paths in the mediation model. Finally, we used a resampling approach to assess the indirect effect of height exposure on presence on the plank through Δfear. The value of the indirect effect was 1.49, bootstrap $SE = 0.57$, 95% CI [0.55, 2.77]. The confidence interval does not include zero, indicating that the indirect effect was positive.

When ΔHR was submitted as the mediator, we again found that the direct effect of height exposure on the presence on the plank was significant, $B = 1.50$, 95% CI [0.43, 2.57], $t(51) = 2.81$, $p = .007$. In addition, ΔHR was significantly related to height exposure, $B = 6.42$, 95% CI [0.30, 12.54], $t(51) = 2.11$, $p = .04$. However, ΔHR was not related to presence on the plank while controlling for the effect of height exposure ($p = .46$). Further, the value of the indirect effect was −0.11, bootstrap $SE = 0.13$, 95% CI [−0.43, 0.08] and because the confidence interval contains zero, these analyses demonstrated no evidence that ΔHR mediated the relationship between height exposure and presence on the plank.

When ΔSCL was submitted as the mediator, we found a significant direct effect of height exposure on the presence on the plank,

Figure 4

Conceptual Model of Mediation With Regression Coefficients for All Paths



Note. The *c* path represents the total effect, *c′* represents the direct effect, and the *a* and *b* paths indicate the mediator's (Δfear) relationship to the antecedent variable (height exposure) and the outcome variable (presence on the plank).

$B = 1.75$, 95% CI [0.51, 3.00], $t(50) = 2.83$, $p = .007$. ΔSCL was significantly related to height exposure, $B = 0.19$, 95% CI [0.11, 0.27], $t(51) = 4.93$, $p < .001$. However, ΔSCL was not related to presence on the plank while controlling for the effect of height exposure ($p = .302$). The value of the indirect effect was −0.37, bootstrap $SE = .40$, 95% CI [−1.53, 0.07], and because the confidence interval contains zero, these analyses demonstrated no evidence that ΔSCL mediated the relationship between height exposure and presence on the plank.

Finally, we attempted to replicate the results from the multiple regression analyses in Study 1, using data from the height condition only. At step 1, presence at baseline predicted presence on the plank, $F(1, 24) = 16.24$, $p < .001$, adjusted $R^2 = .38$. At step 2, the addition of Δfear, ΔHR, and ΔSCL did not result in a significant improvement to the model, $F(3, 21) = 1.74$, $p = .190$, adjusted $R^2 = .43$, $\Delta R^2 = .14$. However, the magnitude of the effect was very similar to that in Study 1 ($\Delta R^2 = .12$), suggesting that the statistical test was affected by the loss of power associated with fewer participants. The standardized beta weights were also very similar to those in Study 1, with Δfear significantly predicting presence on the plank, whereas ΔHR and ΔSCL did not. The semipartial correlation was $r(24) = .49$, $p = .013$, indicated that Δfear uniquely explained a significant proportion of the variance in presence on the plank (Table 7).

General Discussion

The present studies had two aims: first, to demonstrate that height exposure increases both presence and subjective, physiological, and behavioral indices of fear; and second, to test causal mechanisms that might account for the relationship between height exposure and presence. In Study 1, height exposure was associated with a large increase in self-reported fear, anxiety, and presence, as well as a large decrease in self-reported relaxation and happiness. These changes were accompanied by sympathetic activation (i.e., increased HR and SCL). Study 2 replicated the relationship between height exposure and subjective measures of both fear and presence, alongside measures of sympathetic activation. It further showed that people walked more cautiously at height (Kisker et al., 2021), consistent with the motivational priming of defensive behavior in a threatening environment (Lang, 1995). Additionally, the control condition allowed us to attribute those changes to the height manipulation, and not to other aspects of the simulation; although walking the plank in the control condition was associated with small increases in measures of fear and presence, these were much larger in the height condition. The use of virtual heights, in particular, to reliably induce fear has been demonstrated successfully by multiple researchers (Biedermann et al., 2024; Cleworth et al., 2012; Coelho et al., 2009; Gromer et al., 2019; Kisker et al., 2021; Madeira et al., 2021; Nielsen et al., 2022; Schöne et al., 2023) and the current findings dovetail with this existing body of evidence demonstrating how virtual environments can be used to induce emotional responses (Bernardo et al., 2021).

In Study 2, we were able to test causal claims about the effect of fear on presence. Interoceptive accounts (Diemer et al., 2015; Seth et al., 2012) propose that presence arises when physiological changes are consistent with predictions based on perceptions of the environment. In both studies, we found that subjective fear and presence were positively related when exposed to heights, replicating previous studies (Alsina-Jurnet et al., 2011; Bouchard et al., 2008; Gromer et al., 2019; Ling et al., 2014; Peperkorn & Mühlberger, 2013; Peperkorn et al., 2015; Price & Anderson, 2007; Price et al., 2011; Riva et al., 2007; Robillard et al., 2003). In Study 1, we modeled the extent to which subjective and physiological responses consistent with fear-predicted presence at height and found that changes in self-reported fear-predicted presence, whereas sympathetic activation did not. Although self-reported fear was positively correlated with both HR and SCL, showing coherence across response systems, only changes in self-reported fear-predicted presence.

Although other studies have reported relationships between fear and presence, these cannot be used to test causal hypotheses. In Study 2, our experimental mediation showed that the increase in presence caused by height exposure was fully mediated by changes in self-reported fear. In contrast, changes in neither HR nor skin conductance were mediators of the effect. These findings contradict the core tenet of interoceptive accounts (Diemer et al., 2015; Seth et al., 2012) which formalize presence as a function of physiological changes. It is important to note that the current studies did not include any direct measure of interoception, and so it is possible that, while sympathetic activation did not directly affect presence, people's perceptions of their physiological changes might. Indeed, the subjective experience of fear might arise from physiological activity, filtered through interoceptive signals (Critchley & Garfinkel, 2017). Future research should therefore incorporate behavioral measures of interoceptive accuracy or awareness (e.g., Garfinkel et al., 2015), to determine whether interoceptive measures moderate relationships between physiological measures and presence. If these findings replicate even when measures of interoceptive accuracy are taken into account, then this would constitute strong evidence against interoceptive accounts of presence.

How should we interpret the finding that changes in subjective fear can lead us to feel more present? One possibility is that when we introspect about our subjective experience, we tap into a reflective system that ascribes semantic meaning to a situation. This explanation is drawn from the dual-process model of response coherence (Evers et al., 2014) which aims to explain why emotional responses tend to cohere more strongly within systems (i.e., subjective measures relate to other subjective measures and autonomic measures relate to other autonomic measures) but not across systems. Although this dual-process model was formulated to explain emotional responding, response coherence does not apply to emotional responses only (Mauss et al., 2005). Rather, similarly reflective responses might cohere with one another to a greater degree than each would cohere with more automatic responses. Through the lens of this dual-process model, the

Table 7
Regression Analysis: Predicting Presence on the Plank in the Height Condition (n = 26)

Effect	Estimate	*SE*	95% CI LL	95% CI UL	*p*
Intercept					<.001
Baseline presence	0.64	0.16	0.31	0.96	<.001
Intercept					.006
Baseline presence	0.53	0.16	0.20	0.87	.003
ΔFear	0.32	0.16	0.00	0.65	.050
ΔHR	−0.18	0.15	−0.49	0.15	.920
ΔSCL	0.01	0.16	−0.31	0.34	.270

Note. Estimates represent the standardized regression weights. CI = confidence interval; LL = lower limit; UL = upper limit; HR = heart rate; SCL = skin conductance level.

relationship between subjective fear and presence suggests that our sense that we are situated in reality is a reflective feeling informed by the extent to which we experience changes in our subjective emotional state.

Although our hypotheses focused on fear as a mediator of presence, participants also showed increases in anxiety at height. Fear and anxiety are often confusable subjectively and we did not explicitly define these terms for our participants. However, we do believe that people still used different criteria for rating these two emotional states because they reported greater anxiety than fear when first entering virtual reality, but greater fear than anxiety on the plank. It is possible though, that subjective anxiety, and not fear itself, mediated changes in presence. Simulations that specifically target anxiety (i.e., using an ambiguous or unpredictable environment instead of a physical threat; for example, see McCall et al., 2022) would be the best way to determine whether anxiety induces presence independent of fear. Indeed, it is possible that any sufficiently strong emotional response could be causally related to presence. There is some empirical evidence to support this hypothesis; studies using different simulations have shown positive relationships between presence and other emotional states which differ from fear in both valence and arousal and in physiological changes (e.g., relaxation, Baños et al., 2008; sadness, Baños et al., 2004; happiness, Freeman et al., 2005; and awe, Chirico et al., 2018). Future research could draw on the mediational methods, we use here to test causal relationships between presence and other emotional states.

The experimental approach taken here shows that height exposure increases presence, and that increase is mediated by changes in subjective fear. Although we show causal relationships between height and fear and height and presence, we cannot confirm a causal relationship between fear and presence, because it is not possible to manipulate subjective fear directly. Thus, our findings can be used to support causal models but not to confirm them. To establish a causal effect of a mediator, it is necessary to manipulate it directly (Pirlott & MacKinnon, 2016). Because subjective fear cannot be directly manipulated, only induced through environmental manipulations, future studies should use different environmental contexts to induce fear in virtual reality. Converging evidence across methodologies would provide stronger evidence in support of causal inferences.

One limitation of this study is that participants did not have a visual representation of their body in virtual reality. For instance, if participants looked down while on the plank, they would see an empty space where their bodies should be. The fact that we recorded relatively high presence ratings (i.e., average ratings greater than five for all time-windows and conditions) suggests that people still felt present in the virtual environment despite this absence; however, the lack of a corresponding virtual body may have limited the extent to which they felt connected to their physiological state. This limitation may have attenuated any relationship between physiological changes and presence. Therefore, future research should incorporate at least some minimal body representation in the virtual reality simulation.

Although our research was designed to address theoretical questions, our findings have important applications to the design of virtual reality for commercial use. Virtual reality developers strive to maximize users' presence and our findings suggest that one way to effectively induce presence is to manipulate the emotional state of users. Similarly, clinical applications like virtual reality exposure therapy may be improved by manipulating subjective emotional state at targeted points during the therapeutic simulation, for the purpose of maintaining presence throughout the session. Although it was not an aim of the current studies to create better virtual reality, our findings highlight the importance of affective state changes for maximizing and maintaining presence.

It is difficult to know how well findings in virtual reality generalize to the experience of presence in the physical world. Previous research directly comparing responses to height-based virtual environments and their real-world counterparts has demonstrated similar responses across the three components of emotion (Cleworth et al., 2012; Schöne et al., 2023; Simeonov et al., 2005). In terms of presence, Chirico and Gaggioli (2019) found no reliable difference in ratings of physical presence between participants actually standing in front of a mountain lake and participants who experienced the same vista inside virtual reality. These findings suggest that virtual environments can evoke similar emotions and feelings of presence as experiencing the event in the real world, and support claims that experiences induced in virtual reality are authentic. Given the challenges associated with manipulating and measuring presence in the real world, virtual reality at least provides a potentially ecologically valid testing ground for hypotheses.

Our research also highlights the value of virtual reality for testing other relationships between mind, body, and behavior. For example, the causal relationships among physiological changes, subjective feelings, cognitive appraisals, and behavioral tendencies have been debated by emotion theorists for over a century (Barrett, 2017; Cannon, 1929; James, 1884; Schachter & Singer, 1962). The ability to manipulate reality while simultaneously recording physiological (including neural) responses and tracking naturalistic movements and actions paves the way for new experimental and computational approaches for addressing many fundamental questions in cognitive and affective science.

Constraints on Generality

The theories that predict relationships between emotional responses and presence are meant to describe fundamental aspects of human conscious experience. However, our sample consists primarily of healthy young people in Aotearoa New Zealand, and future research in other populations will be necessary to determine if effects generalize to other ages, cultures, or clinical populations. Indeed, such studies will yield important insights about the extent to which these associations are universal and whether they are modulated by relevant group or individual differences.

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