

RESEARCH ARTICLE

The Impact of Adding Multisensory Stimulation to a Fear of Heights Virtual Reality Experience

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ABSTRACT

Introduction: The sense of presence (SP) is a critical factor in eliciting emotional responses during virtual reality exposure therapy (VRET) for treating anxiety disorders. Multisensory stimulation has been suggested as an effective method to enhance the SP in VR environments.

Objective: This study aims to investigate the relationship between SP and anxiety in a VR environment designed to simulate fear of heights (FoH). Specifically, it compares the levels of SP and anxiety experienced in multisensory (i.e., visual, auditory and tactile stimulation) versus bisensory (i.e., visual and auditory stimulation) virtual environments and examines the associations between SP and individual characteristics.

Methods: A total of 162 participants were randomly assigned to one of two experimental conditions: bisensory virtual reality exposure (B-VRE; $n = 85$) and multisensory virtual reality exposure (M-VRE; $n = 77$). Differences in anxiety and SP between the two conditions were assessed using Student's *t*-tests. In addition, correlation, mediation and moderation analyses were conducted to explore the relationships between SP, anxiety, technological features and individual characteristics.

Results: Correlation analyses revealed statistically significant relationships between SP and anxiety during VR exposure, as well as between SP and participants' demographic and personality characteristics. Furthermore, SP partially mediated the relationship between participants' baseline FoH and the anxiety they experienced in the VR environment. Finally, the addition of multisensory cues increased the SP experienced in the virtual scenario but did not significantly impact reported anxiety levels.

Conclusions: Incorporating multisensory feedback to enhance SP during VRET should be considered when designing VR systems for therapeutic use.

Summary

- Adding multisensory cues enhances users' sense of presence in virtual environments.
- Sense of presence partially mediates the link between fear of heights and anxiety during VR exposure.
- Incorporating multisensory elements can improve the effectiveness of VR-based therapy.

1 | Introduction

Virtual reality (VR)-based interventions have proved to be a promising approach for the treatment of several mental disorders

(Emmelkamp and Meyerbröker 2021; Schröder et al. 2023; Wiebe et al. 2022). This technology provides safety, control and adaptability, allowing health professionals to tailor the treatment to the specific needs of each patient, enhancing its

therapeutic potential (Dellazizzo et al. 2020). Virtual reality exposure therapy (VRET) is a prime example of a VR-based intervention and an effective treatment for specific phobias (Carl et al. 2019; Rowland et al. 2022), being comparable with in vivo exposure therapy (Krzystanek et al. 2021; Miloff et al. 2019). The efficacy of VRET lies in its ability to trigger similar physiological and emotional responses as those encountered in real life (Gromer 2021; Meyerbröcker 2021; Ong et al. 2022; Wilczyńska et al. 2024). During VRET, patients are gradually, repeatedly and systematically exposed to virtual simulations of threatening scenarios with the aim of modifying their responses to the feared stimuli and thereby reducing anxiety over time (Freitas et al. 2021; Wiebe et al. 2022).

Sense of presence (SP), defined as the ‘sense of being there’ (Slater et al. 1994), is considered a crucial factor for eliciting anxiety during exposure to virtual scenarios (Alsina-Jurnet et al. 2011; Freitas et al. 2021; Ling et al. 2014; Song et al. 2021; Standen et al. 2023). Presence-induced anxiety allows for emotional processing and habituation, leading to reduced fear responses and thereby facilitating the therapeutic process (Costa et al. 2018; Freitas et al. 2021; Price et al. 2011; Wilczyńska et al. 2024). Thus, a causal relationship between SP and anxious responses when exposed to the feared stimulus or situation has been proposed, stating that ‘[...] presence is the mechanism by which a virtual stimulus can elicit fear [...]’ (Price et al. 2011, 768). However, the relationship between presence and anxiety is complex and still subject to debate (Diemer et al. 2015; Gromer et al. 2019; Riva et al. 2015).

It has been suggested that some features of VR systems may affect the SP experienced in VR environments (Gonçalves et al. 2022; Melo et al. 2020; Shu et al. 2018; Souza et al. 2021). For example, the use of multisensory stimulation has been proposed as an effective method for increasing SP (Marquardt et al. 2018; Wilkinson et al. 2021). Previous research has shown that increasing the number of senses in a VR environment enhances the SP experienced by users (Gonçalves et al. 2022; Hoffman et al. 2023; Melo et al. 2020; Munyan et al. 2016; Ribé-Viñes et al. 2023). The effect of multisensory stimulation on the SP experienced by users during exposure to virtual environments may also influence their emotional response to the virtual situation and, in turn, affect the efficacy of VRET for the treatment of phobias. Thereby, it is necessary to further explore the relationship between multisensory stimulation, SP and anxiety in virtual environments related with phobic fears, as well as how this relationship affects therapeutic outcome.

Users’ characteristics have also been considered to play a role in the SP (Gromer et al. 2019; Gutiérrez-Maldonado et al. 2009; Jicol et al. 2023; Leo et al. 2014; Ling et al. 2013; Souza et al. 2021). Understanding the effect of individual differences in experienced SP is crucial in order to know who are most likely to benefit from VR-based interventions (Alsina-Jurnet and Gutiérrez-Maldonado 2010; Song et al. 2021). Several studies have assessed the relationship between personality-related factors and SP. Extroversion–introversion personality dimension has been found to be associated with SP (Alsina-Jurnet and Gutiérrez-Maldonado 2010; Sas et al. 2004). The *willingness to be transported to a virtual world* has also been proposed as a potential predictor of SP. This willingness enhances the SP, which

in turn may amplify the emotional and physiological responses to virtual scenario (Sas et al. 2004; Servotte et al. 2020; Miegel et al. 2025).

The moderator effect of demographic characteristics, including age, gender and clinical status (i.e., meeting the criteria for an anxiety disorder or not), on presence has also been explored (Felnhofer et al. 2012; Ling et al. 2014). Individuals diagnosed with an anxiety disorder often experience higher levels of presence and stronger fear responses as compared with those without a diagnosis (Ling et al. 2014). The relationship between age and the SP (Lorenz et al. 2023; Stavropoulos et al. 2017) and between gender and SP (Felnhofer et al. 2012, 2014) is more complex and remains inconclusive. Some studies suggest that men may report higher SP, particularly in fear-inducing scenarios, possibly due to greater spatial abilities, familiarity with technology or higher self-efficacy (Felnhofer et al. 2012, 2014; Lachlan and Krcmar 2011). Similarly, findings on age are mixed, with older users sometimes reporting greater SP, potentially because of lower expectations regarding realism or less prior VR experience (Lorenz et al. 2023). These demographic effects may be moderated by individual traits such as immersive tendencies, absorption, spatial abilities, disbelief rejection when experiencing a virtual environment, empathy or previous exposure to VR (Bouchard et al. 2013; Kober and Neuper 2013; Kothgassner et al. 2012; Leo et al. 2014; Ling et al. 2014; Slater et al. 1994), highlighting the need to consider psychological and contextual factors when interpreting SP differences across age and gender.

Given the relevance of the SP for users to experience anxiety in fearful VR environments and the potential effect of such a relationship on VRET efficacy, this study proposes the following goals: (1) to assess the association between SP and anxiety experienced in a fear of heights (FoH)–related virtual environment; (2) to assess the mediating role of SP in the relationship between participants’ FoH and anxiety experienced in the virtual environment; (3) to compare the levels of SP and anxiety experienced by participants exposed to a multisensory (e.g., visual, auditory and tactile cues) versus a bisensory (e.g., visual and auditory cues) virtual reality environment; (4) to assess the association between SP and the participant’s characteristics (i.e., extroversion, willingness to be transported to another world, age and gender); and (5) to assess the moderating role of sensory cues (multisensory vs. bisensory), extroversion, willingness to be transported to a virtual world, age and gender in the relationship between FoH and SP.

Accordingly, the following hypotheses are stated:

1. Correlations between anxiety and presence measures will be positive and significant.
2. SP will mediate the relationship between participants’ baseline FoH and anxiety experienced in the virtual environment.
3. Participants exposed to the multisensory virtual reality environment will experience higher SP and anxiety compared with those exposed to the bisensory virtual reality environment.

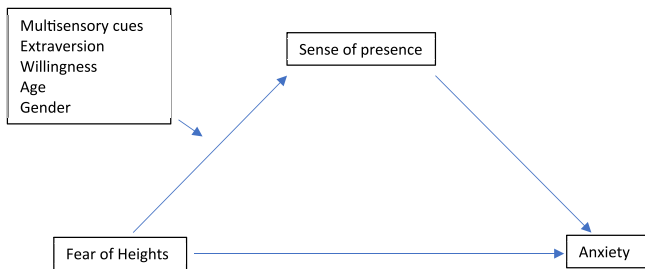


FIGURE 1 | Summary of the proposed mediation and moderation analyses.

4. Participants' characteristics (i.e., extroversion, willingness to be transported to a virtual world, age and gender) will be associated with SP.
5. Sensory cues (multisensory vs. bisensory), extroversion, willingness to be transported to a virtual world, age and gender will moderate the effect of FoH on SP.

Figure 1 shows the moderation and mediation relationships hypothesized in this study.

2 | Method

2.1 | Participants

The sample size was calculated in three steps for the independent samples *t*-test, moderation and mediation analyses. On the one hand, using a priori G*power analysis (Faul et al. 2007) and considering a power of 0.8, in line with Cohen (1992), the total sample size for the independent samples *t*-test and the moderation analysis (calculated by 'F tests: the linear multiple regression, fixed model R2 increase test') yielded a total number of 128 and 105 participants, respectively. On the other hand, given the G*power's limitation in estimating the sample size for mediation analysis, we adopted the number of 71 participants recommended for the bias-corrected bootstrap analysis by PROCESS macro (power = 0.8), by Fritz and MacKinnon (2007). Based on these calculations, a minimum sample size of 130 participants was determined, considering potential dropouts, outliers and missing data.

Adults aged over 18 years old were recruited by advertisements conducted in the faculty of psychology at the University of Barcelona. Participants were screened for eligibility, and those with severe mental disorders, cardiovascular problems, a history of epilepsy, serious medical conditions, ongoing long-term anxiolytic medication or pregnancy were excluded. A total of 164 individuals met the inclusion and exclusion criteria and were initially enrolled in the study. However, two participants were excluded because of incomplete responses on the questionnaires. Therefore, the final sample consisted of 162 participants (103 females, 63.6%; 59 males, 36.4%) with a mean age of 28.59 years (SD = 11.61) and a median of 25 years, ranging from 18 to 74. No incentives for the participants were given.

2.2 | Measures

- **Acrophobia Questionnaire (AQ):** This 20-item self-report questionnaire assesses anxiety and avoidance behaviours associated with height-related situations (Cohen 1977). The anxiety scale, which was used in this study, demonstrates very good internal consistency ($\alpha = 0.86$; Baker et al. 1973). The AQ scores range from 0 to 120, with a score of 48 or higher on the anxiety subscale indicating the presence of FoH. Esquerro et al. (2010) validated the questionnaire for use in the Spanish population. In the present study, the anxiety subscale exhibited excellent internal consistency ($\alpha = 0.90$).
- **State-Trait Anxiety Inventory (STAI):** The STAI is a 40-item self-report instrument designed to assess both state anxiety (STAI-S) and trait anxiety (STAI-T). STAI-S measures the anxiety experienced in response to specific external situations, whereas STAI-T reflects a more stable, enduring tendency to perceive situations as threatening (Spielberger et al. 1970). Each subscale consists of 20 items, with responses rated on a 4-point Likert scale ranging from 0 (no anxiety) to 3 (high anxiety). In this study, the STAI-S subscale was administered before and after VRE to assess anxiety experienced in the virtual scenario, and it demonstrated excellent internal consistency (STAI-S: $\alpha = 0.92$).
- **Eysenck Personality Questionnaire Revised-Abbreviated (EPQR-A):** The EPQR-A is a 48-item self-report questionnaire designed to assess four personality dimensions: extraversion, neuroticism, sincerity and psychoticism (Francis et al. 1992). The EPQ's scales have undergone several revisions to improve the assessment of orthogonal and reliable personality traits (Quilty and Oakman 2004). Specifically, the four-factor structure of the Spanish version of the EPQR-A (Sandín et al. 2002) demonstrated adequate internal consistency and factorial validity, particularly for the extraversion scale ($\alpha = 0.74$). In this study, six items from the extraversion scale were used, yielding an acceptable internal consistency ($\alpha = 0.78$).
- **Willingness to be transported into a virtual world (W)** was assessed by asking participants to rate their willingness on a scale ranging from 0 to 100 (Crichton 2001). A high level of willingness to be transported into a virtual reality experience (Sas 2004) is considered essential for achieving a high level of spatial presence in virtual environments (Slater and Usoh 1993).
- **Slater-Usuh-Steed Questionnaire (SUS):** The SUS measures the degree of presence that individuals experience in a virtual reality environment (Usuh et al. 2000). The questionnaire consists of six open-ended questions, each scored on a scale from 1 to 7, with interpretation varying based on the nature of the question. In this study, the SUS was administered after VRE to assess the level of presence experienced in the virtual scenario.
- **Anxiety and SP experienced during exposure to the virtual reality environment** were assessed by means of subjective units of discomfort ranging from 0 to 100 in the case of anxiety (VRE-A) and the question 'To which extent do you feel present in the virtual environment' with a range from 0 to 100 (Bouchard et al. 2004) in the case of SP (VRE-SP).

2.3 | Experimental Design

An independent measures design was used, also referred to as a between-subjects design, with two experimental conditions: bisensory virtual reality exposure (B-VRE) and multisensory virtual reality exposure (M-VRE). In the B-VRE condition, participants were exposed to the same VR environment intended to evoke FoH, receiving only visual and auditory stimuli. In contrast, the M-VRE condition included visual, auditory and tactile stimuli. Participants were randomly assigned to either the B-VRE or M-VRE condition, with 85 participants in the B-VRE group and 77 in the M-VRE group.

2.4 | Hardware

The hardware used included an HTC Vive head-mounted display (HMD) with a 1080×1200 pixel resolution and a 1000-Hz tracking frequency, providing satisfactory levels of immersion (Mehrfard et al. 2019; Standen et al. 2023). The HMD was powered by a Microsoft Windows PC and operated on the SteamVR software platform (<https://www.steamvr.com/es/>).

To provide tactile stimulation in the M-VRE condition, participants were required to walk on a real wooden plank (width: 19 cm; depth: 4 cm; length: 151 cm) that replicated the shape of the virtual one (Kisker et al. 2019; Krupić et al. 2021). Although participants wore shoes, the slight elevation and narrow width of the wooden plank allowed them to feel the surface and edges underfoot, enhancing tactile realism during the virtual exposure. Additionally, a fan was used to simulate wind from outside the virtual elevator (Ibrahim et al. 2008).

2.5 | Virtual Environment

The software used during the exposure session was developed by SmartVR Studio. The virtual environment, titled ‘Top Floor’, was designed to induce FoH. Participants began the experiment inside an elevator located on the ground floor of a tall skyscraper, with glass walls offering a clear view of the street below as the elevator ascended to the top floor. Upon reaching the top, participants exited the elevator and were given approximately 1 min to familiarize themselves with their surroundings. Following this brief acclimatization period, they proceeded to walk along a virtual plank for about 1 min before eventually falling off the plank within the virtual environment. Throughout the entire experience, participants had a 360° field of view, allowing them to freely move their heads in all directions—side to side, forward and backward. The examiner was able to monitor participants’ interactions with the virtual environment via a computer display (see Figure 2).

2.6 | Procedure

After the initial screening, participants who met the inclusion criteria were scheduled for their individual session of the experiment. Upon signing the informed consent form, they provided demographic information. Participants were then randomly



FIGURE 2 | Virtual exposure set up during participants’ virtual experience.

assigned to either the B-VRE or M-VRE group using the Random Allocation Software (MathWorks, <https://www.mathworks.com>; Hwang 2024). Following group assignment, participants completed the AQ, EPQ-R-A and W questionnaires, which assessed FoH, extroversion and willingness to engage with the virtual environment, respectively.

Upon completion of the questionnaires, participants stood as the HMD was meticulously positioned on their heads. After activating the virtual display, participants could interact with the virtual environment. During the exposure, the researcher remained nearby to provide assistance if needed. The virtual exposure lasted approximately 2 min, and the entire session, including the administration of all questionnaires, took around 30 min.

Anxiety levels were measured before, during and after the virtual experience. Specifically, the STAI-S was administered immediately before and after the virtual exposure. Additionally, subjective anxiety (VRE-A) and SP (VRE-SP) were assessed at three key points during the exposure: (1) when the elevator

reached the first floor (VRE-A1, VRE-SP1), (2) when the elevator reached the top floor as the participant prepared to step out (VRE-A2, VRE-SP2) and (3) while the participant walked on the plank (VRE-A3, VRE-SP3). At each point, participants rated their anxiety and SP on a scale from 0 to 100. Finally, after the exposure, SP and anxiety experienced during the virtual experience were assessed using the SUS and STAI-S questionnaires.

2.7 | Bioethics Committee Approval

This study was approved by the Bioethics Committee of the University of Barcelona (IRB00003099).

2.8 | Statistical Analysis

Statistical analyses were conducted using IBM SPSS (version 27.0.1.0) and the Hayes PROCESS macro (version 4.2), following a five-step process aligned with the present research objectives. First, Pearson's correlation analyses were performed to examine the relationship between the SP and anxiety experienced in the virtual reality environment. Second, the mediating role of SP in the relationship between participants' FoH and anxiety during the VRE was assessed using the PROCESS macro, Model 4 (Hayes 2017). FoH, measured by the AQ, was included as the independent variable, SP (assessed with the SUS) as the mediator and the various anxiety measures during (VRE-A1, VRE-A2, VRE-A3) and after the VR exposure (STAI-S-Po) as the dependent variables. Third, Student's *t*-tests were used to assess differences in SP and anxiety between participants in the B-VRE (bisensory stimulation) and M-VRE (multisensory stimulation) groups. Fourth, Pearson's correlation analyses were conducted to evaluate the association between SP and participants' characteristics, including extroversion, willingness to be transported to a virtual world and age. To assess the relationship between SP and gender (categorical variable), point-biserial correlations were applied. Finally, the Hayes PROCESS macro, Model 1 (Hayes 2017), was employed to assess whether sensory cues (multisensory vs. bisensory), extroversion, willingness to be transported to a virtual world, age and gender moderated the relationship between FoH (independent variable) and SP

(dependent variable). In all analyses, kurtosis and skewness values indicated normal distributions for all variables. The significance level was set at $p=0.05$.

3 | Results

As shown in Table 1 and consistent with the first hypothesis, all correlations between SP and anxiety experienced during exposure to the virtual environment (VRE-A1, VRE-A2, VRE-A3) were positive and significant, though the effect sizes were mostly small. However, the correlations between SP and anxiety measured with the STAI-S were not significant. These findings suggest that SP is linked to anxiety responses in height-related virtual environments. Specifically, participants who reported a greater SP in the virtual scenario experienced higher levels of anxiety during the exposure. The strongest associations between SP and anxiety were observed when participants were walking on the virtual plank (VRE-A3), with a medium effect size.

To explore the relationship between SP and anxiety further, a second goal was to assess the mediating role of the SP (measured with the SUS) in the relationship between FoH (measured with the AQ) and anxiety experienced during the VRE (VRE-A1, VRE-A2, VRE-A3), as well as after the VR exposure (STAI-S). Table 2 presents a summary of the mediation analyses.

The results indicated that both the direct effect (FoH → VRE-A) and the indirect effect (FoH → SP → VRE-A) of FoH on anxiety experienced during the virtual environment exposure were significant. This suggests that SP partially mediated the relationship between FoH and anxiety during the exposure. However, when anxiety was assessed after the exposure (STAI-S), only the direct effect of FoH on anxiety was significant, with no mediation effect observed.

A primary objective of this study was to assess the effect of increasing the number of senses stimulated in the VR environment on SP experienced by users. With this aim, the levels of SP (assessed with the VRE-SP and the SUS) and anxiety (assessed with the VRE-A and the STAI-S) experienced in the bisensory virtual reality environment (B-VRE) were compared with the levels experienced in the multisensory condition (M-VRE).

TABLE 1 | Correlations between SP and anxiety measures.

	VRE-A1		VRE-A2		VRE-A3		STAI-S	
	<i>r</i>	<i>r</i> ²	<i>r</i>	<i>r</i> ²	<i>r</i>	<i>r</i> ²	<i>r</i>	<i>r</i> ²
VRE-SP1	0.343**	0.12	0.269**	0.07	0.193*	0.04	0.077	0.006
VRE-SP2	0.201*	0.04	0.350**	0.12	0.291**	0.08	0.096	0.01
VRE-SP3	0.164*	0.03	0.237**	0.06	0.524**	0.27	0.013	0.0001
SUS	0.279**	0.08	0.293**	0.08	0.407**	0.16	0.139	0.02

Note: *r*² (effect size: 0.10, small; 0.20, medium; 0.30, large; Brydges 2019; Gignac and Szodorai 2016).

Abbreviations: STAI-S-Po (State-Trait Anxiety Inventory-State); SUS (Slater-Usch-Steed Questionnaire); VRE-A1 (anxiety during virtual reality exposure, first assessment time); VRE-A2 (anxiety during virtual reality exposure, second assessment time); VRE-A3 (anxiety during virtual reality exposure, third assessment time); VRE-SP1 (sense of presence during virtual reality exposure, first assessment time); VRE-SP2 (sense of presence during virtual reality exposure, second assessment time); VRE-SP3 (sense of presence during virtual reality exposure, third assessment time).

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

TABLE 2 | Mediation analyses summary, where FoH is the independent variable, anxiety is the dependent variable, and SP is the mediation variable.

Hypotheses	Total effect (<i>p</i> -value)	Direct effect (<i>p</i> -value)	Indirect effect	Confidence interval		Conclusion
				Lower bound	Upper bound	
FoH → SP → STAI-S	0.2784 (<0.001)	0.2704 (<0.001)	0.0080	−0.0070	0.0262	NM
FoH → SP → VRE-A1	0.7630 (<0.001)	0.7122 (<0.001)	0.0507	0.0070	0.1054	PM
FoH → SP → VRE-A2	0.6583 (<0.001)	0.5948 (<0.001)	0.0635	0.0079	0.1384	PM
FoH → SP → VRE-A3	0.6901 (<0.001)	0.5762 (<0.001)	0.1139	0.0214	0.2249	PM

Abbreviations: FoH (fear of heights); NM (no mediation); PM (partial mediation); SP (sense of presence); STAI-S (State-Trait Anxiety Inventory-State); VRE-A1 (anxiety during virtual reality exposure, first assessment time); VRE-A2 (anxiety during virtual reality exposure, second assessment time); VRE-A3 (anxiety during virtual reality exposure, third assessment time).

TABLE 3 | Mean (M), standard deviation (SD) and independent samples *t*-test results for SP (VRE-SP3 and SUS) and anxiety (VRE-A3 and STAI-S) scores of participants in bisensory and multisensory stimulation groups.

	B-VRE group M (SD)	M-VRE group M (SD)	<i>t</i>	<i>p</i>	Cohen's <i>d</i> *
VRE-A3	60.00 (28.13)	67.44 (25.31)	−1.745	0.083	−0.278
STAI-S	21.34 (11.08)	18.57 (9.37)	1.708	0.089	0.269
VRE-SP3	73.30 (22.23)	80.58 (18.59)	−2.230	0.027	−0.355
SUS	29.38 (5.30)	28.58 (6.21)	0.875	0.383	0.138

Abbreviations: B-VRE group (bisensory stimulation group); M-VRE group (multisensory stimulation group); STAI-S (State-Trait Anxiety Inventory-State); SUS (Slater-Usch-Steed Questionnaire); VRE-A3 (anxiety during virtual reality exposure, third assessment time); VRE-SP3 (sense of presence during virtual reality exposure, third assessment time).

*The effect size (Cohen's *d*) is interpreted as small (0.2), medium (0.5) and large (0.8).

Following Ling et al. (2014), only the highest scores of anxiety and SP experienced during exposure to the virtual environment (i.e., VRE-A3 and VRE-SP3, corresponding to the moment that the participant walks on the virtual plank) were included in this analysis. Contrary to the hypothesis, no significant differences in anxiety scores between the B-VRE and M-VRE groups were found. By contrast, the M-VRE group reported significantly higher SP during the exposure to the virtual scenario ($p=0.027$), although the effect size was small (Cohen's $d=-0.355$). No differences between groups were found when SP was assessed after the exposure, using the SUS. Table 3 summarizes these results.

To analyse the potential influence of user characteristics on SP, the relationships between extroversion–introversion personality dimension (EPQR-A-E), willingness to be transported to a virtual world (W), age and gender with SP were also examined. Pearson's correlation analyses revealed a positive and significant relationship between age and SP when measured using the SUS scale ($r=0.175$, $p=0.026$), with a small effect size ($r^2=0.03$; Brydges 2019; Gignac and Szodorai 2016). However, this association was not significant when SP was assessed using the 0–100 rating scale (VRE-SP1: $r=0.126$, $p=0.109$; VRE-SP2: $r=0.136$, $p=0.084$; VRE-SP3: $r=0.138$, $p=0.081$). These findings indicate that higher SP, as measured by the SUS, is associated with older age.

TABLE 4 | Mean scores in SP measures in men and women.

	Gender	
	Men (<i>n</i> = 59) M (SD)	Women (<i>n</i> = 103) M (SD)
VRE-SP1	57.31 (23.38)	67.83 (20.99)
VRE -SP2	64.69 (19.92)	71.48 (20.50)
VRE -SP3	72.20 (21.80)	79.62 (19.77)
SUS	26.97 (5.79)	30.17 (5.42)

Abbreviations: SUS (Slater-Usch-Steed Questionnaire); VRE-SP1 (sense of presence during virtual reality exposure, first assessment time); VRE-SP2 (sense of presence during virtual reality exposure, second assessment time); VRE-SP3 (sense of presence during virtual reality exposure, third assessment time).

Regarding personality traits, the correlation between extraversion and SP experienced by participants while walking on the platform in the VR environment was positive and statistically significant, although the effect size was small (VRE-SP3: $r=0.186$, $p=0.019$, $r^2=0.03$). The more extroverted the participants were, the higher the SP they showed. However, correlations between extraversion and the remaining SP measures were not significant (VRE-SP1: $r=-0.024$, $p=0.763$; VRE-SP2: $r=0.081$, $p=0.308$; SUS: $r=0.043$, $p=0.586$). Correlations between the

TABLE 5 | Moderation analyses summary, where the moderator effect of the sensory cues used, extroversion, willingness to be transported to another world, age and gender on the relationship between FoH and SP was assessed.

Hypotheses	Interaction coefficient	<i>t</i> -statistics	<i>p</i> -value	Confidence interval		Conclusion
				Lower bound	Upper bound	
FoH*SC → SP	−0.0960	−1.565	0.120	−0.2171	0.0251	NM
FoH*E → SP	0.0149	0.914	0.362	−0.0173	0.0470	NM
FoH*W → SP	0.0006	0.423	0.673	−0.0022	0.0033	NM
FoH*Age → SP	−0.0033	−1.720	0.087	−0.0071	0.0005	NM
FoH*G → SP	0.0418	0.566	0.572	−0.1042	0.1879	NM

Abbreviations: E (extroversion); FoH (fear of heights); G (gender); NM (no moderation); SC (sensory cues); SP (sense of presence); W (willingness to be transported into a virtual world).

willingness to be transported to a virtual world and the SP were also positive and statistically significant (VRE-SP2: $r=0.183$, $p=0.020$, $r^2=0.03$; VRE-SP3: $r=0.157$, $p=0.048$, $r^2=0.02$; SUS: $r=0.194$, $p=0.013$, $r^2=0.03$), except for VRE-SP1 ($r=0.078$, $p=0.327$). In all cases, the effect size was small. These findings indicate that the greater the willingness to be transported, the higher the reported SP.

Point-biserial correlations were conducted to examine the relationship between gender and SP. The results indicated a statistically significant positive association between gender and all SP measures (VRE-SP1: $r_{pb}=0.227$, $p=0.004$, $r^2=0.05$; VRE-SP2: $r_{pb}=0.160$, $p=0.042$, $r^2=0.03$; VRE-SP3: $r_{pb}=0.173$, $p=0.030$, $r^2=0.03$; SUS: $r_{pb}=0.269$, $p<0.001$, $r^2=0.07$), with a small effect size (Brydges 2019; Gignac and Szodorai 2016). As shown in Table 4, women reported a greater SP than men, both during and after exposure to the virtual environments.

Further, this study also aimed to explore the moderating roles of the VR system's (i.e., sensory cues: multisensory vs. bisensory) and the user's (i.e., extraversion, willingness to be transported to another world, age and gender) characteristics in the relationship between FoH and SP. As shown in Table 5, none of the assessed variables significantly moderated the relationship between FoH and SP.

The absence of interaction effects suggests that the relationship between baseline FoH and SP is consistent regardless of the number of sensory cues included in the virtual environment and the characteristics of participants. These factors do not significantly alter how FoH influences the SP in the virtual environment.

4 | Discussion

This study aimed to deep into the relationship between SP and anxiety experienced in heights phobic-related virtual environments, as well as the effect of individuals' and technology's characteristics on presence, especially the use of multisensory versus bisensory stimulation.

To this end, several objectives were set. First, the association between SP and anxiety experienced in a FoH-related environment was assessed. As expected, results showed a positive

relationship between the two variables when anxiety was measured during exposure to the virtual scenario (VRE-A). However, no relationship was found between SP (assessed both during and after the VRE) and anxiety measured after exposure (STAI-S). This discrepancy aligns with previous research suggesting that the association between presence and anxiety is stronger during the VR experience than after it, likely due to the emotional immediacy and contextual congruence present only during exposure (Ling et al. 2014; Price and Anderson 2007). The discrepancy between anxiety scores measured during the virtual exposure (VRE-A) and those recorded afterward (STAI-S) may be attributed to the timing and context of each measure. Although VRE-A captures immediate, immersive fear responses, the STAI-S is administered postexposure, when participants are no longer in a threatening context and may experience cognitive reappraisal or relief, leading to lower anxiety ratings. This suggests that subjective units of discomfort (rated on a scale from 0–100) may be a more accurate self-report instrument for assessing anxiety during exposure than the STAI-S. These findings are consistent with previous studies that provided evidence supporting the association between SP and anxiety experienced in fear-induced virtual scenarios (Freitas et al. 2021; Ling et al. 2014; Song et al. 2021).

It is worth noting that, in the present study, the strongest association between presence and anxiety was observed when these variables were assessed while participants walked along the virtual plank (VRE-A3), the point of exposure when participants showed the highest levels of anxiety (Kisker et al. 2019). Several studies have highlighted the bidirectional nature of the relationship between presence and anxiety (Bouchard et al. 2008; Gromer et al. 2019; Robillard et al. 2003), suggesting that an increase in presence leads to an increase in anxiety, and vice versa. This feedback loop between the two variables may explain why their correlation intensifies in more fear-provoking situations.

SP has been recognized as a key factor for users to experience anxiety in virtual scenarios (Alsina-Jurnet et al. 2011; Ling et al. 2014; Price et al. 2011). In turn, experiencing a certain level of anxiety is considered essential for VRET to be effective (Costa et al. 2018; Lognoul et al. 2020; Price et al. 2011; Wilczyńska et al. 2024). Therefore, exploring the role of the SP in generating anxiety during VRE is critical. With this aim, the study assessed the mediating role of the SP in the relationship between baseline

FoH and anxiety experienced during (VRE-A) and immediately after (STAI-S) exposure to a height-related virtual environment. According to the results obtained, the SP partially mediates the relationship between participants' baseline FoH and the anxiety reported during exposure to the virtual scenario (Scheveneels and Carpentier 2024). These findings indicate that anxiety experienced in phobia-related VR environments is influenced not only by how fear-inducing the situation is for the user but also by the SP experienced during the exposure (Standen et al. 2023). The clinical implications of these findings are significant, as they suggest that for a VR system to be effective in VRET, it must present the appropriate phobic stimuli (Alsina-Jurnet and Gutiérrez-Maldonado 2010; Bouchard 2008) and evoke a sufficient—though not necessarily strong—level of presence to elicit an emotional anxiety response (Bouchard et al. 2012; Price and Anderson 2007; van Loenen et al. 2022). Therefore, adjusting the SP through advanced VR technologies should be considered an important factor in enhancing the therapeutic outcomes of VRET for anxiety disorders.

It is also worth noting that the relationship between presence and anxiety may not be strictly linear. As suggested in previous literature, an S-shaped curve might better represent this relationship (Bouchard et al. 2008; Gromer et al. 2019; Robillard et al. 2003), where moderate levels of presence lead to steep increases in anxiety, but higher levels may result in a ceiling effect. This nonlinear dynamic highlights the need to identify an optimal presence range for therapeutic efficacy without necessarily maximizing immersion.

Previous research has suggested that stimulating multiple senses during VR exposure enhances the realism and plausibility of the environments, which in turn increases the experienced SP (Marquardt et al. 2018; Marucci et al. 2021; Melo et al. 2020; Wilkinson et al. 2021). In line with this, the third and primary aim of this study was to determine whether multisensory cues (i.e., visual, auditory and tactile) would increase SP and anxiety in the VR environment compared with bisensory cues (i.e., visual and auditory). As expected, participants in the multisensory VRE (M-VRE) group reported significantly higher levels of SP, as measured by the SUS, than those in the bisensory VRE (B-VRE) group. These findings are consistent with previous studies, which also showed that adding multiple sensory modalities (beyond visual) enhances SP (Gonçalves et al. 2022; Hecht et al. 2006; Melo et al. 2020; Munyan et al. 2016).

Contrary to the hypothesis, no significant differences were found in anxiety levels between participants in the M-VRE and B-VRE groups. These results contrast with previous research that suggested that vibrotactile stimulation increases anxiety in virtual environments (Zhao et al. 2021). However, the present findings are consistent with studies by Miri et al. (2022), Raether (2022) and Umair et al. (2021), which also did not observe this relationship. Given that participants were from a nonclinical population, it is possible that although the inclusion of haptic feedback enhanced their SP, it did not significantly impact anxiety levels. In fact, only 7% ($n = 12$) of participants in this study showed FoH (AQ scores ≥ 48). This may suggest that individuals without clinical phobias experience heightened presence from haptics without corresponding increases in anxiety, unlike those with more severe fear responses.

This study also assessed the relationship between individuals' characteristics and SP. Results showed a significant and positive association between SP and extraversion and the willingness to be transported to a virtual world, although effect sizes were small, and significance was not achieved at all assessment points. Previous research has reported a positive relationship between SP and the willingness to be transported or to feeling immersed in VR (Sas et al. 2004; Servotte et al. 2020).

The present findings agree with Kim et al. (2016) and Laarni et al. (2004), who observed that extraverted participants reported higher levels of SP in positive or neutral emotionally triggering virtual scenarios. Conversely, these results conflict with those of Alsina-Jurnet and Gutiérrez-Maldonado (2010), Sas et al. (2004) and Thornson et al. (2009), who found that more introverted participants experienced higher levels of SP. It has been suggested that both introversion and extraversion may influence the virtual reality experience, depending on the virtual environment's context, the type of emotions triggered and the specific dimension of presence being assessed (Gutiérrez-Maldonado et al. 2009; Kim et al. 2016). In addition, although the exposure was conducted individually, the experimental setting can still be considered a social context (e.g., participant–researcher interaction), which may have different implications for introverts and extraverts. Therefore, personality traits might not only influence how presence is experienced in the virtual world but also how participants perceive the broader context of the experimental situation.

The relationship between SP and users' demographic characteristics (i.e., age and gender) was also examined in this study. Interestingly, women and older participants reported higher levels of SP compared with men and younger users. These findings contradict the common belief that SP is typically higher in men and tends to decline with age (Lorenz et al. 2023), as men and younger individuals are often thought to have more experience with VR (Leo et al. 2014). However, existing research presents inconsistent data. Regarding gender, studies by Felnhöfer et al. (2012) and Sagnier et al. (2020) reported higher levels of SP in men, whereas Lorenz et al. (2023) found no significant gender differences. Likewise, the potential impact of the characteristics of the sample should also be considered and the VR scenario used on results. First, although the participants' ages ranged from 18 to 74, only 25.9% were over 30 years old and just 8.6% were above 40. As a result, it is likely that most of them were familiar with virtual reality technology. Second, a large proportion of the participants were women (63.6%). Further research is needed to explore whether specific VR content and features could account for differences in various dimensions of presence based on gender. In particular, future studies should consider the role of cognitive and physiological factors, task context and prior VR experience in shaping gender-related differences in SP. Including longitudinal designs and objective physiological measures may help clarify whether such differences are stable, context-dependent or mitigated over time.

Although this research did not identify a singular pattern in the interactions between age-SP and gender-SP due to the multitude of factors that interact within these associations, the results show that patients' responses to VRE may be influenced by demographic characteristics. And, most importantly, this

influence may change depending on the virtual stimulus within the situation. Finally, the lack of interaction between FoH and the moderator variables suggests that although sensory cues and individuals' characteristics might independently affect presence (Felnhofer et al. 2012; Gamito et al. 2010; Ling et al. 2014; Sacau et al. 2008), they do not modify the specific relationship between participants' FoH and their SP in the acrophobia-related virtual scenario.

Summarizing this study expands available evidence about the relationship between SP and anxiety in phobia-related virtual environments and its potential effect on VRET. Results suggest that the addition of multisensory cues (i.e., visual, auditory and tactile) may increase the SP experienced by patients during VRET for FoH and, in turn, facilitate the elicitation of anxiety responses, a critical requisite for the efficacy of exposure therapy.

Despite the significance of these findings, this study has several limitations that should be addressed. First, a convenience sample consisting primarily of college students was used, and consequently, findings cannot be generalized to clinical populations. Despite the lack of clinical sample and formal diagnosis, these findings provide valuable insights into the underlying mechanisms that contribute to the efficacy of VRET and may offer practical relevance to clinicians interested in adopting VRET as part of their clinical interventions. Second, only self-reported measures were included. Although self-reported measures for assessing anxiety are widely accepted and generally demonstrate good reliability and validity (Rose and Devine 2014), the inclusion of psychophysiological measures could provide more objective data of the anxiety experienced (Wiederhold et al. 2001, 2002). Third, in this study, the SP was assessed using the SUS (Usoh et al. 2000) and a 0–100 scale. Future research should adopt a broader conceptualization of presence, beyond just spatial presence, to determine which specific components influence users' emotional responses in VREs. Additionally, further studies should explore how technological advancements could enhance the overall SP in VR. Fourth, one of the objectives of this study was to assess the impact of individual and technological characteristics on SP experienced in the virtual environment. However, many other personality traits and user-related variables may also influence the VR experience and should be considered in future research (Song et al. 2021). Lastly, regarding demographic characteristics, a broader age range in the sample would have been needed to properly analyse its effect on SP.

5 | Conclusion

This study provides valuable insights regarding the relationship between SP and emotional responses in FoH-related virtual environments, a key factor for the efficacy of VRET. The findings suggest that anxiety experienced during VRE is influenced not only by pre-existing phobic fears but also by the degree to which an individual feels 'present' in the virtual scenario. This reinforces the idea that increasing SP is critical for the effective management of anxiety in VRET. Moreover, the results indicate that incorporating multisensory cues into virtual environments can enhance the SP during VRET, which should be considered

when designing VR systems for therapeutic purposes. Finally, the study highlights the complex relationships between individuals' personality traits, demographic characteristics and their experienced SP. Understanding these relationships is essential for optimizing the effectiveness of VRET and developing tailored VR-based interventions.

Author Contributions

José María Ribé-Viñes: conceptualization, methodology, formal analysis, investigation, writing – original draft, resources, data curation, writing – review and editing. **Marta Ferrer-García:** conceptualization, methodology, data curation, formal analysis, writing – reviewing and editing, supervision. **Zahra Zabolipour:** formal analysis, data curation, writing – reviewing and editing. **Miriam Aguilar-Gil:** formal analysis, data curation. **José Gutiérrez-Maldonado:** supervision, writing – reviewing.

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Ethics Statement

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the University of Barcelona on March 6, 2024.

Consent

Informed consent was obtained from all individual participants included in the study.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data used to support the findings of this study are included within the article and are available from the corresponding author upon reasonable request.

Human and Animal Rights

This article does not contain any studies with human or animal subjects performed by any of the authors. The present study was approved by the bioethics committee of the University of Barcelona. This systematic review is part of a larger study approved by the bioethics committee of the *Universitat de Barcelona* (IRB00003099).

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