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Virtual reality exposure with vibrotactile stimulation for the treatment of fear of flying: A pilot study

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A R T I C L E I N F O

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A B S T R A C T

Background and objectives: Virtual reality (VR) interventions are becoming more prevalent in treating fear of flying (FoF). Since multisensory stimulation can enhance the sense of presence in a virtual environment, the present study compared virtual reality exposure with and without vibrotactile cues to determine its contribution to the realism of the virtual experience.

Methods: A repeated measures design was used. Thirty-one participants were exposed to two experimental conditions with a minimum of a one-week interval between them: one in which participants were exposed to the virtual environment with vibrotactile cues (smart chair, SC), and another in which participants were exposed to the virtual environment without vibrotactile cues (ordinary chair, OC). The administration order of both conditions was counterbalanced to avoid possible order effects.

Results: Participants felt higher levels of sense of presence when using the SC than the OC. However, the addition of vibrotactile stimulation partially influenced experienced anxiety. Some personality traits were also associated with participants' sense of presence and anxiety responses during the exposure.

Limitations: The sample size was smaller than required. Moreover, only self-reported measures were used. Finally, a roller coaster instead of an airplane scenario was used for the exposure, which might not have been suitable enough for provoking anxiety in participants with FoF.

Conclusions: Vibrotactile cues enhanced the sense of presence. However, the addition of vibrotactile stimulation did not have a consistent effect on anxiety experienced during exposure. Therefore, the benefits of incorporating vibrotactile cues in virtual reality environments for exposure therapy are not clear.

1. Introduction

Fear of Flying (FoF) is a psychological challenge, defined by the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) as an "intense fear or anxiety about flying situations" (American Psychiatry Association, APA, 2013). Despite its categorization as a situational-specific phobia (APA, 2013), FoF can stem from diverse fears such as heights or loss of control (Bados López, 2017). Nearly 25% of the general population experiences flying-related anxiety, with around 20% resorting to alcohol or anxiolytics and approximately 10% avoiding flying due to severe fear (Khatua & Pattanaik, 2018; Oakes & Bor, 2010). FoF exhibits the highest treatment-seeking rate among specific phobias, highlighting the need for effective evidence-based therapies (Wardenaar et al., 2017).

Exposure therapy is the leading intervention for phobias, including FoF (Wechsler et al., 2019). Grounded in the theory of extinction learning (Kaczkurkin & Foa, 2022), exposure therapy gradually exposes individuals to feared stimuli, resulting in the reduction or extinction of irrational fears through habituation. The process involves activating the emotional network associated with fear, challenging unrealistic and catastrophic expectations. While in vivo exposure and imagery exposure are established exposure therapy methods, new technologies offer opportunities to enhance treatment outcomes (Morina et al., 2015; Opriş et al., 2012; Powers & Emmelkamp, 2008). Virtual reality exposure therapy (VRET) emerges as an impactful (Cárdenas et al., 2016; Carl et al., 2019; Serrano et al., 2019) and cost-effective approach for specific phobias, specially FoF (Miloff et al., 2016) demonstrating a significant anxiety reduction post-treatment (Cardoş et al., 2017; Mühlberger et al., 2003, 2006).

Sense of presence, defined as 'the sensation of being in the location

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depicted by virtual reality, as opposed to the participant's actual physical location' (Sheridan, 1996; Slater & Wilbur, 1997), is pivotal for successful VRET (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Wiederhold & Wiederhold, 2005). Individuals need to emotionally engage in anxiety-inducing virtual environments for an effective treatment (Maples-Keller et al., 2017), and feeling present in the virtual scenario is a fundamental prerequisite for this to occur. Consequently, ensuring that the virtual environment takes precedence over the physical reality becomes imperative for the effectiveness of VRET (Benbow & Anderson, 2019; Gromer et al., 2019; Krijn et al., 2004; Meyerbröker, 2021).

However, the relationship between sense of presence, the emotional engagement, and the efficacy of exposure therapy is complex and not clearly established. Thus, despite some studies suggesting a positive link between a heightened sense of presence and more robust treatment outcomes (Price & Anderson, 2007; Robillard et al., 2003; Wiederhold & Wiederhold, 2005), a significant correlation between these two factors might not always be recognized (Miloff et al., 2019; Price et al., 2011; Price & Anderson, 2007; Tardif et al., 2019). Previous research has proposed that correlations between presence and anxiety levels could indeed impact treatment outcomes (Price et al., 2011) and, accordingly, several studies have found positive associations between the sense of presence and treatment effectiveness (Parsons & Rizzo, 2008; Price & Anderson, 2007; Schuemie et al., 2000), but other studies report mixed findings (Krijn et al., 2004; Ling et al., 2012; Villani et al., 2012). Moreover, moderating factors, such as technological aspects and research design, may affect the interplay between the sense of presence and anxiety in the context of FoF and the utilization of VRET (Ling et al., 2014).

Incorporating multiple sensory cues, beyond visual and auditory stimuli, have been proposed as a suitable way to enhance the sense of presence in the virtual environments and, hence, optimize VRET. According to Kaul et al. (2017), Serrano et al. (2016), and North and North (2016), vibrotactile cues can foster a heightened sense of presence and immersion within virtual worlds, as these cues can serve as stimuli capable of evoking fear. Likewise, other studies have explored the impact of incorporating diverse sensory signals encompassing tactile, visual, and auditory cues within the same virtual environment on the sense of presence (Cooper et al., 2018; Marquardt et al., 2018; Marucci et al., 2021; Ribé-Viñes et al., 2023). Despite the previous statement, the relationship between these sensory cues and the sensation of presence isn't universally consistent, as some existing research (Krijn et al., 2004) has not consistently found a definitive connection.

Although the existing research presents a varied relationship between specific personality characteristics and the sense of presence (Kober & Neuper, 2013; Laarni et al., 2004), individual differences significantly shape the way one perceives presence within virtual environments (Lombard & Ditton, 1997). Understanding these individual disparities in relation to the sense of presence is crucial, as they can aid in identifying patients who are most likely to benefit from VR-based treatments (Alsina-Jurnet & Gutiérrez-Maldonado, 2010).

This study aimed to determine whether adding vibrotactile stimulation to a VR environment simulating a roller coaster increased the sense of presence and anxiety in a non-clinical population. This environment was chosen because it induces similar psychophysiological activation as aircraft environments (Busscher et al., 2013). The effect of personality characteristics and the FoF of participants on the reported sense of presence and anxiety experienced in the virtual situation were also explored.

To this end, we hypothesize that:

(1) participants exposed to the virtual environment will experience a greater sense of presence and anxiety when using the SC compared to when using an ordinary chair (OC).
(2) participants with FoF (vs. participants without FoF) will experience higher sense of presence and anxiety when exposed to the virtual environment, especially, when using the SC compared to when using the OC.
(3) greater empathy (E), absorption (Ab), trait anxiety (TA), and willingness to be transported in a virtual environment (W) will be associated with higher anxiety levels and sense of presence, especially when using the SC.

2. Method

2.1. Participants

The sample size was calculated using a prior G*power analysis (Faul et al., 2007) based on a partial η^2 of 0.196 taken from Klosters (2019) and a power of 0.8 in line with Cohen (1992), for paired sample t-tests analyses. This analysis led to a total sample size of 34 participants.

Thirty-five participants were recruited through advertisements in social network groups of different universities in Barcelona (Spain), and through personal contacts of the research team. The inclusion criteria consisted of individuals aged 18 or older who were able to read and understand the Spanish questionnaires administered in the study. Those with severe mental disorders, cardiovascular problems, a history of epilepsy, a serious concomitant medical condition, currently undergoing long-term anxiolytic medication, or pregnant were excluded. As 4 participants dropped out of the study for personal reasons, the final sample (N) included 31 participants with a mean age of 27.3 years (SD = 9.3).

According to the Spanish version of the Fear of Flying Questionnaire-II (QPV-II, Tortella-Feliu & Fullana Rivas, 2000), 10 participants showed FoF (score ≥90) and 21 did not (scores< 90). However, none of them had a FoF diagnosis or had prescribed medications or psychotherapy for treating their fear. Table 1 shows the sociodemographic information of the sample.

2.2. Measures

1. **State-Trait Anxiety Inventory (STAI):** The STAI assesses both state anxiety (SA) and trait anxiety (TA). SA refers to anxiety experienced in response to external situations, while TA represents a relatively stable anxious disposition where individuals tend to perceive circumstances as threatening (Spielberger et al., 1970). The inventory consists of 40 Likert-type items, with 20 items for the SA scale and 20 for the TA scale. Participants rate each item on a scale from 0 (absence of anxiety) to 4 (much anxiety). In this study, both SA and TA scales demonstrated high internal consistency (α = 0.89).
2. **Fear of Flying Questionnaire-II:** To assess participants' FoF, a modified version of the Fear of Flying Questionnaire (QPV) was used. The QPV-II comprises 30 items, each representing a situation related

Table 1
Demographic information of participants.

	Results
Order Effect	(n = 31)
OC + SC	14
SC + OC	17
Age	(n = 31)
Mean (SD)	27.323 (9.261)
Median (Q1-Q3)	25 (23–27)
Gender	(n = 31)
Male	13 (41.94)
Female	18 (58.06)
Marital Status	(n = 31)
Single	29
Married	2
Educational Status	(n = 31)
Secondary school	4
University education	13
Postgraduate education	14

Note: OE = Order Effect; OC = Ordinary chair; SC = Smart Chair.

to flying by plane that induces anxiety. Participants rate each item on a scale from 1 (minimum anxiety) to 10 (maximum anxiety) (Bornas & Tortella-Feliu, 1997). The QPV-II exhibited high internal consistency in this study (α = 0.96).

3. **Visual Analogic Scale for assessing anxiety (VAS-A):** The VAS-A measures an individual's level of anxiety at a specific time, using a scoring scale from 1 (scant anxiety) to 100 (extreme anxiety) (Crichton, 2001). This scale was employed three times during each exposure session to assess participants' perceived anxiety.
4. **Slater-Usoh-Steed Questionnaire (SUS):** The SUS evaluates the degree of presence experienced by individuals in the VR environment they are exposed to (Usoh et al., 2000). The questionnaire consists of six open-ended questions, and each question is scored on a scale from 1 to 7, with the interpretation based on the nature of the question. In this study, the SUS was administered after the virtual exposure to assess the level of presence in the virtual scenario. The SUS demonstrated a Cronbach's Alpha of 0.70 in this study.
5. **Tellegen Absorption Scale (TAS):** The TAS measures an individual's openness to experiencing imaginal or sensory events, which, in this experiment, refers to the virtual world (Tellegen & Atkinson, 1974). The scale comprises 34 dichotomous items, and participants respond with either "yes" or "no" based on their experiences. This scale was introduced to the participants during the first exposure session. In the original study, the TAS exhibited high internal consistency with a Cronbach's Alpha of 0.88.
6. **Interpersonal Reactivity Index (IRI):** The IRI is a self-report questionnaire that assesses the ability to share someone else's feelings in their situation. Consists of 28 items, each rated on a scale from 1 (does not describe me) to 5 (describes me very well). According to Sas (2004), empathy (E) is a potential personal factor that is involved in the sense of presence. This questionnaire was administered during the initial exposure session to assess participants' level of E, and demonstrated good internal consistency with a Cronbach's Alpha of 0.74.
7. **Willingness to be transported into a virtual world:** This component assesses participants' willingness to engage in a VR experience (Sas, 2004). This trait is considered necessary for experiencing a high level of sense of presence (Slater & Usoh, 1993). Participants were asked to rate this trait on an analogue visual scale (VAS-T) before the exposure session.

2.3. Experimental design

A repeated measures design was employed, where participants experienced two experimental conditions. In the first condition (SC), participants were exposed to the virtual environment using a head-mounted display (HMD) and the smart chair (HMD + SC). In the second condition (OC), participants were exposed to the virtual environment using the HMD and an ordinary office chair (HMD + OC). All participants experienced both conditions with a minimum one-week interval between sessions. To minimize potential order effects, the order of exposure to conditions SC and OC was counterbalanced, as recommended by Brooks (2012); so 17 participants were exposed to the condition SC during the first session and the condition OC during the second session, while 14 participants were exposed to the condition OC during the first session and to the condition SC during the second session. Participants were randomized assigned to one of the two groups (SC/OC or OC/SC).

2.4. Hardware

In both exposure sessions, the hardware used for exposure to the virtual environment included the HMD and the SC (Fig. 1). The HMD consisted of a Google CardBoard VR headset, a smartphone Huawei P30 LITE (Kirin 710 processor, 6 GB RAM and FHD 2312 × 1080 resolution screen), and headphones (Pioneer DJ HDJ CUE1 with insulating material). Despite its limitations, the Cardboard VR provides acceptable level of immersion compared to higher-end VR devices like the Oculus Rift (Amin et al., 2016; Patel et al., 2019). Moreover, is significantly less expensive and easier to use, being a suitable option for VR-based psychological interventions administration.

Fig. 1. Smart chair set up when the participant was exposed to the virtual reality environment.

The smart chair, also known as a sensorial processing chair (SPxThrone model, manufactured by Sensorial Processing Tech Barcelona; www.sptbcn.com/), is equipped with vibrational actuators distributed throughout the chair framework, delivering vibrotactile stimuli through a motherboard (ARDUINO MEGA 2560, 5 V, 16 MHz) in synchronization with auditory and visual cues from the virtual environment. This device consists of several electromagnetic components which transform auditory to vibrotactile cues and distributes them synchronously to the vibrational actuators (2 × Subwoofers, 4 Ω, 2 W, 100–4000 Hz, 2 × Speakers Alnica de 2,5″, 2 W 8 Ω 66 × 66, 2 × Speaker Generic, 4 W 8 Ω, 100 Hz a 20 kHz, 2 × DC MOTOR FK260 SA 10.400 DE 6–24 V) embedded throughout the chair framework conveniently positioned according to the anatomy of the human body. The kind of stimulation provided by the SC have been previously proved to enhance the sense of presence experienced by the user in the virtual setting (Soave et al., 2020).

The chair's computer motherboard has two modes: smart and ordinary. In the smart mode, the chair emits vibrotactile inputs around the back and legs of the individual, synchronized with auditory cues from the virtual roller coaster situation. In contrast, the ordinary mode involves the same chair but with the motherboard switched off, resulting in no vibrotactile cues being generated around the chair. The SC allows for lateralized intensity fluctuations based on the individual's motions within the virtual world (left or right). The intensity of vibrations could be adjusted depending on the virtual environment's pace and slope, with higher intensity experienced during faster and steeper movements. In this study, the researcher adjusted the mode assigned to each participant by turning the motherboard on or off accordingly.

2.5. Virtual environment

The software used in the exposure sessions consisted of a previously recorded 360-degree view video, providing an authentic experience that was limited to the filmmaker's camera movements. 360-degree videos have proved to be effective in VRET for treating phobias in previous research (Flobak et al., 2019; Gelsomini et al., 2017; Meinel et al., 2017).

About to start the virtual ride, participants found themselves situated in the front row of the roller coaster, offering them a 360-degree interactive experience as they could freely turn their heads in different directions - side to side, forward, and backward. Within a few seconds, the ride initiated, and participants were taken through the circuit. The journey featured exhilarating climbs and thrilling descents, accompanied by tangible vibrations generated by the wagon's traction. The virtual experience concluded as the wagon gradually decelerated until it came to a complete stop.

2.6. Procedure

Following the initial screening, participants who met the inclusion criteria were scheduled for the first session of the experiment. During this initial session, and once the informed consent was signed, participants provided demographic data and completed a battery of tests. Then, participants were randomly assigned to one of the following groups: SC/OC or OC/SC, using the common method of coin flips (Kang et al., 2008). The 10 participants exhibiting FoF were distributed 6 in the SC/OC group and 4 in the OC/SC group.

Both first and second exposure sessions followed the same structure. Participants sat in the chair and the HMD were set up. Once the virtual display started, participants were able to interact with the virtual environment. During exposure, the researcher remained next to the participants to assist them if required, and once finished the exposure help them to remove the electronic devices they were holding. The virtual exposure lasted 2 min. The exposure sessions were carried out in a quiet office belonging to a psychology clinic and each session lasted up to 30 min in total.

Anxiety levels were assessed before, during and once finished the virtual experience. Specifically, the STAI-S was administered just before and after the exposure to the virtual environment. Moreover, subjective anxiety (VAS-A) was assessed at three relevant points during the exposure: 1) when the roller coaster car was about to descend on the first circuit (VAS-A1), 2) when the car went through the tunnel (VAS-A2), and 3) when the ride circuit ended (VAS-A3). Prior to the exposure, participants were given instructions to verbally communicate their level of anxiety (ranging from 0 to 100) at these three specific points. Likewise, the sense of presence experienced during the virtual experience was assessed through the SUS after the exposure.

2.7. Bioethics committee approval

The present study was approved by the bioethics committee of the University of Barcelona.

2.8. Statistical analysis

All statistical analyses in this study were conducted employing SPSS Version 25.0 (SPSS, Inc., Chicago, Illinois). Paired samples and independent samples t-tests were performed in order to examine the two first hypotheses. The independent variables were *FoF* (presence or absence of fear of lying) and *chair mode* (SC or OC) and the significance level (p-value) was set at 0.05 in all analyses. The Kolmogorov-Smirnov test showed that the data were normally distributed in all variables. Regarding the third hypothesis, the Pearson correlation was conducted in order to evaluate the association between TA, Ab, E, W, sense of presence, and anxiety. To examine potential order effects, independent samples t-tests were conducted to compare the results of all assessed variables between participants in Group SC/OC and Group OC/SC.

3. Results

Paired and independent-samples t-tests were conducted to assess the effect of the chair mode (SC vs. OC) and the presence or absence of FoF (FoF vs. no FoF) on the anxiety and sense of presence reported by participants during and after exposure to the virtual environment.

Considering the first hypothesis, paired samples t-tests were conducted to compare the sense of presence and anxiety levels when participants used the SC compared to when they used the OC. The results showed a significant difference in the sense of presence when using the SC ($M = 27.68$, $SD = 7.79$) compared to the OC ($M = 24.26$, $SD = 7.23$), $t(30) = 2.70$, $p = .01$). The mean increase in the test scores was 3.42 with a 95% confidence interval ranging from 0.84 to 6. Moreover, The Cohen's d (0.49) indicated a medium effect size (Cohen, 1988). In other words, the sense of presence was moderately higher when using the SC in comparison to the OC.

In terms of the anxiety levels, our findings showed that during the VR exposure there was a significant difference in the anxiety levels between using the SC ($M = 56.94$, $SD = 23.08$) and the OC ($M = 46.65$, $SD = 22.84$), $t(30) = 2.97$, $p = .006$, but only when the ride was about to go down the circuit (VAS-A1). The mean increase in the test scores was 10.29 with a 95% confidence interval ranging from 3.21 to 17.37. The Cohen's d (0.53) also indicated a large effect size (Cohen, 1988). The anxiety level when the virtual ride was about to go down the circuit was much higher when using the SC rather than the OC. However, results indicated a non-significant difference in the anxiety levels after being exposed to the virtual environment (STAI-S) between using the SC ($M = 26.87$, $SD = 4.76$) and the OC ($M = 27.26$, $SD = 3.85$), $t(30) = -0.57$, $p = .57$. The anxiety levels after the virtual environment exposure were similar in both conditions. Therefore, the first hypothesis was partially supported.

Regarding the second hypothesis, independent samples t-tests were conducted to compare the sense of presence and anxiety levels during (VAS-A) and after (STAI-S) the exposure to the virtual environment between participants with and without FoF. The results showed a non-significant difference ($t(29) = -0.43$, $p = .67$) in sense of presence scores between participants with FoF ($M = 25.90$, $SD = 7.99$) and participants without FoF ($M = 24.57$, $SD = 8.03$). In terms of the anxiety level during the exposure to the VR, no significant differences were observed between participants with and without FoF in any of the VAS-A subscales (VAS-A1, VAS-A2, VAS-A3). In other words, no significant difference ($t(29) = -0.64$, $p = .53$) was found in the anxiety level when the ride was about to go down the circuit (VAS-A1) between participants with FoF ($M = 54$, $SD = 25.47$) and without FoF ($M = 48.10$, $SD = 23.21$). The difference in the anxiety level when the car went through the tunnel (VAS-A2) between subjects with ($M = 38.50$, $SD = 22.12$) and without FoF ($M = 33.57$, $SD = 22.31$) was not significant either ($t(29) = -0.58$, $p = .57$). Moreover, no significant difference ($t(29) = 0.18$, $p = .86$) was observed in the anxiety level when the ride circuit ended (VAS-A3) between participants with FoF ($M = 31$, $SD = 20.38$) and participants without FoF ($M = 32.38$, $SD = 19.28$). Moreover, there was no significant difference ($t(29) = 1.01$, $p = .32$) in anxiety scores, after being exposed to the virtual environment, between participants with FoF ($M = 25.60$, $SD = 3.27$) and participants without FoF ($M = 27.24$, $SD = 4.56$). Regardless of the chair mode, participants with and without FoF experienced similar sense of presence and anxiety levels, indicating that the sense of presence and anxiety rates are independent from the FoF variable.

Paired samples *t*-test were also conducted to evaluate the impact of the SC on the sense of presence and anxiety levels during (VAS-A) and after (STAI-S) the exposure to the virtual environment in participants with FoF (Table 2). The results showed a non-significant difference in the sense of presence when using the SC compared to the OC ($p > .05$). In other words, the sense of presence was similar in participants with FoF, when using the SC compared to the OC (SC: $M = 28.60$, $SD = 7.12$, OC: $M = 26$, $SD = 7.89$). Findings also indicated a non-significant difference

Table 2
Mean (M) and standard deviation (SD) scores for sense of presence and anxiety of participants during and after the exposure to the virtual environment.

	OC		SC	
	noFoF M(SD)	FoF M(SD)	noFoF M(SD)	FoF M(SD)
STAI – S	27.33 (4.09)	27.10 (3.51)	26.71 (5.20)	27.20 (3.91)
SUS	23.43 (6.95)	26 (7.89)	27.24 (8.23)	28.60 (7.12)
VAS – A1	43.62 (22.42)	53 (23.59)	52.86 (21.77)	65.50 (24.55)
VAS – A2	32.14 (22.83)	37.50 (23.72)	34.10 (24.41)	45 (22.73)
VAS – A3	30.52 (22.01)	28 (22.14)	25.76 (15.67)	27.70 (11.91)

Note: FoF = Presence of FoF; noFoF = Absence of FoF; M = Median; SD = Standard deviation; STAI-S = STAI State scale; SUS = Slater-Usoh-Steed Questionnaire; VAS-A1 = VAS scale during the first assessment; VAS-A2 = VAS scale during the second assessment; VAS-A3 = VAS scale during the third assessment.

in the anxiety levels when using the SC compared to the OC, among participants with FoF ($p > .05$). Therefore, the anxiety levels were similar when using the SC and the OC in participants with FoF (SC: $M = 27.20$, $SD = 3.91$, OC: $M = 27.10$, $SD = 3.51$) and the third hypothesis was rejected. In other words, participants experienced the same level of sense of presence and anxiety regardless of the presence or absence of FoF.

Finally, the relationship between personality variables with anxiety and sense of presence experienced in the virtual environment were also explored. As indicated in Table 3, there was a positive and significant correlation between W and the sense of presence when using the SC (r = .44; p = .01), whereas when using the OC, the same correlation was not significant (r = 0.18; p = .34). A marginally significant and positive correlation was also observed between E and the sense of presence (r = 0.35; p = .05) when using SC, whereas when using the OC the same correlation was not significant (r = 0.24; p = .19). On the one hand, significant and positive correlations were found between W and anxiety during the exposure when using the SC. Specifically, W was significantly and positively correlated to the anxiety during virtual exposure (VAS SC1: r = 0.39, p = .03; VAS SC2: r = 0.48, p = .006; VAS SC3: r = 0.44, p = .01). On the other hand, when using the OC, the only significant and positive correlation was found between Ab and anxiety during virtual exposure when the ride circuit ended (r = 0.48, p = .007). No other significant correlation was observed. Thus, the third hypothesis was partially supported.

Table 3
Correlations between personality variables (empathy, absorption, trait anxiety, and willingness to be transported in a virtual environment) and anxiety and sense of presence experienced in the virtual environment when using the OC and the SC.

	W		Ab		E		TA	
	r	p	r	p	r	p	r	p
STAI-S SC	.15	.42	−.02	.90	.12	.51	.31	.09
STAI-S OC	.03	.87	−.17	.35	.11	.55	.06	.76
SUS SC	.44	**.01**	.10	.58	.35	**.50**	.21	.26
SUS OC	.18	.34	.15	.41	.24	.19	.11	.55
VAS SC1	.39	**.03**	.25	.17	.002	.99	.02	.90
VAS SC2	.48	**.006**	.15	.43	−.002	.99	−.21	.25
VAS SC3	.44	**.01**	.22	.24	.27	.13	.24	.18
VAS OC1	.26	.15	.02	.90	−.11	.55	−.08	.66
VAS OC2	.33	.07	−.07	.70	−.02	.93	−.28	.12
VAS OC3	.24	.18	.48	**.007**	.10	.58	.31	.09

Note: r = Pearson correlation, p = significance index, STAI-S SC = STAI state scores after the exposure with the SC, STAI-S OC = STAI state scores after the exposure with the OC, SUS SC = Sense of presence after the exposure with the SC, SUS OC = Sense of presence after the exposure with the OC, VAS SC = VAS scores during the exposure with the SC, VAS OC = VAS scores during the exposure with the OC.

4. Discussion

The main aim of this study was to determine whether adding vibrotactile stimulation to a VR environment simulating a roller coaster increased the sense of presence and anxiety in a non-clinical population. Sense of presence is considered a critical factor for emotional engagement in the virtual scenarios (Wiederhold & Wiederhold, 2005), which is in turn an essential prerequisite for the effectiveness of VRET (Maples-Keller et al., 2017). Consequently, increasing sense of presence in virtual environments used in clinical setting, have been proposed as a suitable way to improve VR-based treatment outcomes (Price & Anderson, 2007; Robillard et al., 2003).

Consistent with our first hypothesis, the scores obtained from the self-reported SUS questionnaire confirmed that participants experienced a higher sense of presence with the SC compared to the OC, providing support to the effect of vibrational stimulation in increasing the sense of presence during VRE. This finding aligns with previous research that has explored the role of vibrational stimulation in enhancing the sense of presence in VR (Lee et al., 2017; Soave et al., 2020; Zhao et al., 2021). However, it is worth noting that some clinical trials which used motion bases (Mühlberger et al., 2001) or bass speaker (Rothbaum et al., 2006) to simulate sensory information did not report a significant contribution to VRET. In the current study, the SC's vibrational actuators with lateralized intensity fluctuations could have led to experiencing more sense of presence.

Regarding the first hypothesis, it was also expected that the SC would significantly increase anxiety experienced during (VAS-A) and after (STAI-S) exposure. However, the results revealed a non-significant relationship between the SC and the anxiety scores. Participants experienced similar anxiety levels with and without vibrotactile cues. These results are inconsistent with previous research that found that the addition of vibrotactile stimulation was associated with higher anxiety in virtual environments (Kim et al., 2019; Zhao et al., 2021). Nevertheless, in accord with our findings, other authors did not find such relationship (Miri et al., 2022; Raether, 2022; Umair et al., 2021).

A secondary objective of this study was to explore the effect of individual differences, such as the fear of flying and personality traits, on the reported sense of presence and anxiety in the virtual situation. Previous studies has unveiled a bidirectional relationship between emotions and presence (Gromer et al., 2019; Riva et al., 2007). This signifies that higher levels of presence not only heighten individuals' emotional responses within the virtual environment but also, conversely, an emotionally impactful environment prompts a heightened sense of presence among participants. Accordingly, it was expected that participants with fear of flying reported to feel more present and to experience more anxiety in the virtual roller coaster than participants with no fear of flying, given the similar psychophysiological activation between this situation and the flying-related environments (Busscher et al., 2013).

However, the presence of fear of flying had no effect in the sense of presence and anxiety experienced in the virtual scenario in this study. Thus, both participant with and without fear of flying showed similar levels of sense of presence and anxiety in the SC and SO conditions. Only subjective anxiety reported when initiating the first ride go down of the roller coaster's circuit (VAS-A1) was significantly higher in the SC condition than in the OC condition in the group of participants with FoF. These results are not in line with the findings of Clark and Rock (2016), who claimed that since the mechanical vibrations were perceived as threatening, individuals with FoF would feel more present and anxious in the virtual environment. Two factors may explain results found. On the one hand, participants in the FoF group were not patients with a diagnosis of flying phobia. Given that, despite reporting fear of flying when answering the QPV-II, the emotional response to the roller coaster scenario was not as intense as expected. On the other hand, the roller coaster may not be a suitable virtual environment to reproduce the same responses as a flying situation. Although it has been reported that both situations produces similar psychophysiological activation (Busscher et al., 2013), the roller coaster is usually associated with entertainment. Consequently, the scenario may be perceived more as an exciting than as a frightening situation.

Another objective of this study was to explore whether individual differences may affect the sense of presence and anxiety experienced in the virtual environment. It has been previously stated that the *willingness to be transported to a virtual world*, empathy, absorption, and trait-anxiety are potential predictors of the degree of sense of presence experienced in a virtual environment (Fehribach et al., 2021; Sas, 2004). Accordingly, a strong association between the willingness to be transported to a virtual world and the sense of presence experienced in the virtual environment when using the SC was found in this study. Likewise, higher levels of willingness to be transported to a virtual world was associated with higher levels of anxiety experienced during the exposure to the virtual environment (VAS-A), but only in the SC condition. Hence, individuals with a greater willingness to be transported to a virtual environment are more likely to experience a higher degree of anxiety and sense of presence in a virtual scenario with vibrotactile cues. Empathy shows a similar pattern with the SC, where higher levels of empathy are associated with a greater sense of presence, but only when vibrotactile stimulation is added. Surprisingly, participants with higher absorption were those who reported higher anxiety levels but only when finishing the roller coaster's circuit in the OC condition.

Our findings contribute to establishing a link between individuals' characteristics and their experience in virtual environments (Kober & Neuper, 2013; Sacau et al., 2008; Sas, 2004) and add evidence to the statement that personality traits and individual differences should be considered when using VR scenarios with clinical purposes (Alsina-Jurnet & Gutiérrez-Maldonado, 2010). Specifically, this study highlights the significance of factors such as the willingness to be transported to a virtual world and empathy as possible contributors to the levels of sense of presence when using vibrotactile stimulation. However, results found are still inconsistent and more research is needed to understand how users' personal characteristics may affect their response to VR-based treatments (Aranha et al., 2018). Thus, individuals who are less prone to engage in anxiety-inducing virtual environments may not experience the emotional reactions necessary for effective VRET.

Summarizing, the results of this study suggest that the addition of vibrotactile stimulation by means of the SC, increases the sense of presence in the virtual environment. Moreover, psychological characteristics such as willingness to be transported to a virtual world and empathy are associated with higher presence experienced in multisensory virtual environments. Nevertheless, these findings should be considered taking into account the limitations of the study. First, the sample size was smaller than required, as four participants quit the study. This issue was especially relevant when groups of participants with and without FoF were established. Thus, future research should be conducted with wider sample sizes. Second, the group of FoF consisted of subclinical population, as was established on the bases of the scores obtained in the Fear of Flying Questionnaire-II, but not on a clinical diagnosis. This fact could have been contributed to the non-significant differences between groups. Third, the lack of anxiety differences between participants with and without FoF also suggests that the employed roller coaster scenario was not suitable for assessing an airplane experience. Consequently, future studies may use more specific scenarios. Fourth, the use of a repeated measures design involves potential issues related with order effects (Rogers & Revesz, 2019). To minimize these negatives effects, conditions were counterbalanced (Brooks, 2012; Rogers, 2017) and a minimum of one week between the administration of the first experimental condition and the second one was established. Fifth, although previous research has used psychophysiological data such as heart rate variability and blood pressure as an objective measure of anxiety (Wiederhold et al., 2001, 2002), in this study, only self-reported measures were used to assess the emotional responses of participants during their exposure to the virtual environment. Thus, future researchers are encouraged to include the objective measures in order to reduce the risk of bias. Finally, a Google CardBoard VR headset and a smartphone Huawei P30 LITE were used for exposure to the virtual environment. Despite studies showing that the Cardboard VR provides acceptable level of immersion compared to higher-end VR devices like the Oculus Rift (Amin et al., 2016; Patel et al., 2019), it has significant limitations that may have affected the sense of presence experienced by the participants in the virtual environment. Future research should consider the use of more suitable devices such as Oculus Rift or Vive Pro.

5. Conclusion

This study shows that by integrating vibrotactile cues from the SC, along with auditory and visual cues, the sense of presence (but not anxiety) is heightened compared to exposure to a virtual environment without vibrotactile cues. It has been suggested that the sense of presence is a necessary mediator for emotions to be activated in virtual environments (Parsons & Rizzo, 2008; Price et al., 2011) and, consequently, that a heightened sense of presence could contribute to enhance the effectiveness of VRET.

Recent analyses about the application of VR in the clinical field have shown that VR costs are steadily declining and it is becoming more affordable for clinical practices (Rizzo & Koenig, 2017). However, the relationship between the sense of presence and the efficacy of VR-based treatments is still not clear (Miloff et al., 2019; Price et al., 2011; Tardif et al., 2019). Future research should address if the inclusion of multisensory cues in VRET for FoF contributes to the efficacy of the treatment through sense of presence and associated emotional responses.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of University of Barcelona the 5th of October 2020.

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Consent to participate

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

Consent to publish

Consent to publish was obtained from all individual participants included in the study.

CRediT authorship contribution statement

J.M. Ribé-Viñes: Writing – original draft, Conceptualization, Data curation, Methodology, Writing – review & editing. **J. Gutiérrez-Maldonado:** Supervision, Validation. **Zahra Zabolipour:** Formal analysis, Methodology, Supervision, Writing – review & editing. **M. Ferrer-Garcia:** Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors have no relevant financial or non-financial interests to disclose.

Data availability

Data will be made available on request.

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