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RESEARCH PAPER

Validation of a virtual environment for sexual aversion

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Abstract This study focused on sexual aversion (SA) — namely the experience of fear, disgust, and avoidance when exposed to sexual contexts or cues — and aimed to validate a virtual environment's ability to progressively trigger the typical emotional responses of SA. Thirty-nine participants (16 low-SA and 23 high-SA individuals) were immersed in a virtual room and then successively exposed to six scenarios in which a synthetic character showed erotic behaviors of increasing sexual intensity. Throughout immersion, subjective measures of anxiety and disgust (Subjective Units of Discomfort Scale; SUDS), skin conductance, heart rate, cardiac output, and eye movements were recorded. The changes in SUDS and physiological variables were examined through repeated measures analyses of variance. SUDS scores significantly increased as the levels of exposure progressed among the high-SA participants, who also reported significantly more anxiety and disgust than the low-SA group. Significant large time effects were found for cardiac output and eye fixation (on face, chest, and genitals), but no significant group*time interactions were found for physiological variables. Results show that this virtual environment may be a promising tool for research and practice, and its efficacy as part of a virtual reality exposure-based treatment for SA should be tested.

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Introduction

Sexual Aversion (SA) disorder is defined as a persistent or recurrent extreme aversion to, and avoidance of, all or almost all, genital sexual contact with a sexual partner, causing distress or interpersonal difficulties (American Psychiatric Association, 2000). Aversive sexual cues can include aspects of partenered sexual activities (e.g., penetration, bodily fluids, sexual intimacy), perceptions surrounding sexuality (e.g., nudity, sexual communication, fantasies, sexual health messages), or masturbation (Borg, de Jong, & Elgersma, 2014; Brotto, 2010). SA is associated with psychological and sexual distress (Bodenmann & Ledermann, 2008; Hendrickx, Gijs, & Enzlin, 2016), reduced sexual and relationship satisfaction (Tripoli et al., 2011; Vaillancourt-Morel et al., 2015), as well as other sexual difficulties (e.g., sexual desire disorders; Borg et al., 2014; Hendrickx et al., 2016). In severe SA cases, exposure to sexual stimuli may also cause panic symptoms (e.g., heart palpitations, shortness of breath; Borg et al., 2014). Even though SA has been removed as a distinct disorder in the transition from DSM-IV-TR to DSM-5 (American Psychiatric Association, 2013; Borg et al., 2014; Reed et al., 2016), prevalence data suggest that SA is far from uncommon. In an online survey ($n = 4147$) among a representative sample of adults (aged 19—69 years), 30% of respondents reported experiencing SA at least once in their lives and about 4% met DSM-IV-TR diagnostic criteria for SA disorder (Bakker & Vanwezenbeek, 2006). A more recent population-based study ($n = 8000$) conducted among a representative Dutch sample (aged 15—71 years), revealed that women were twice as likely as men to experience persistent SA (4.5% and 2.4%, respectively; Kedde, 2012). Among a clinical sample of patient seeking sex therapy ($n = 220$), 11.8% of women and 1.0% of men reported consulting for SA (Lafrenaye-Dugas, Hébert, & Godbout, 2020). Together, these findings suggest that SA may be quite prevalent, with ratios comparable to other common sexual disorders (e.g., genito-pelvic pain; Hendrickx et al., 2016; Kedde, 2012).

Several developmental and psychological factors have been associated with SA, such as childhood sexual abuse history (Noll, Trickett, & Putnam, 2003; Vaillancourt-Morel et al., 2016), performance anxiety (Gold & Gold, 1993), insecure attachment (Jore, Green, Adams, & Carnes, 2016), and negative body image (de Jong & Borg, 2015; La Rocque & Cioe, 2011). Janata & Kingsberg, 2005 suggest that the development and maintenance of SA could be explained by Mowrer (1960) *Two-Factor Theory* of fear acquisition and maintenance: the Pavlovian conditioning model would explain the development of SA by the pairing of a neutral or positive stimulus (sexuality) with aversive or traumatic stimuli (e.g., performance anxiety, attachment insecurities, sexual abuse), whereas operant conditioning would explain the maintenance of SA by negative reinforcement of sexual avoidance. Furthermore, Barlow's feedback loop model for sexual difficulties (Barlow, 1986; Wiegel, Scepkowski, & Barlow, 2007) offers comprehensive insight into the cognitive, emotional and physiological mechanisms maintaining SA, including: (a) a sense of losing control in the sexual situation; (b) hypervigilance to signs of sexual arousal perceived as anxiety-provoking or unsatisfying; (c) a shift of attention to self, associated with a perceived incapacity to cope with the sexual situation; (d) significant physiological activation of the autonomic and endocrine nervous systems, maintaining a state of vigilance and preparing for avoidance.

Considering the hypothesized etiological factors of SA (e.g., sexual abuse, performance anxiety), it is likely that following one or several sexual experiences associated with distressing emotions, one would tend to avoid sexual activity (Gold & Gold, 1993), which will ultimately contribute to interfering thoughts and apprehensions about sex, decreasing one's ability to focus on erotic cues and to experience satisfactory sexual arousal and physical intimacy (de Jong, van Overveld, & Borg, 2013). This conceptualization of cognitive and behavioral mechanisms involved in the development and persistence of SA may explain why exposure-based therapy is documented as effective in treating this condition (Borg, Both, ter Kuile, & de Jong, 2020). Exposure can take various forms (e.g., *in vivo*, imaginal, interoceptive), but typically involves controlled, progressive, and repeated exposure to anxiety-provoking stimuli (without avoidance) in view of gradually reducing their ability to trigger the conditioned fear response (Meuret, Wolitzky-Taylor, Twohig, & Craske, 2012). During virtual reality exposure-based therapy specifically (i.e., *in virtuo*), patients are immersed in a virtual environment in which they are exposed to a virtual representation of the threat (Baus & Bouchard, 2014).

Most VR treatments for mental disorders are based on the principles of exposure-based therapy. Previous research documented the efficiency of VR exposure-based treatment for several disorders, such as anxiety disorders, eating disorders, posttraumatic stress disorders, or substance disorders (for reviews, see Carl et al., 2019; Freeman et al., 2017). In the treatment of specific phobias and other anxiety disorders, a meta-analysis (Powers & Emmelkamp, 2008) even suggests that VR exposure-based therapies could be more effective than *in vivo* exposure (i.e., facing the actual stimulus or a physical representation of it). Yet, sexual dysfunctions have largely been neglected in empirical VR research (Freeman et al., 2017; Lafortune, Dion, & Renaud, 2020). More precisely, we only found a single series of uncontrolled studies in the late 1990s (Optale et al., 1997, 1998), examining the efficacy of a psychoanalytic VR therapy protocol in improving erectile disorder and premature ejaculation. Since then, although no study specifically examined the relevance of VR for SA or sexual dysfunctions, studies have supported its relevance in the broader field of sexual health. For instance, preliminary data (Silva et al., 2019) suggests that VR could be included in future biofeedback interventions for pelvic floor disorders (e.g., urinary incontinence, pelvic organs prolapse) or genital pain disorders (e.g., dyspareunia), since it could provide a less stressful and more intuitive way of strengthening perineum muscles during rehabilitation physiotherapy rehabilitation, compared to traditional treatment. Based on their study results on the *body-sex-change illusion*, Tacikowski, Fust, and Ehrsson (2020) suggested that among individuals with gender dysphoria, and who consider hormonal therapy and gender reassignment surgery, future VR experiences (e.g., assisted with 3D body scanners) could alleviate distress and allow for the experience of their own ''new body'' before undergoing irreversible medical transition. In the context of paraphilic disorders, VR was found to be a reliable tool for accurately assessing sexual fantasies and preferences among child molesters (Marschall-Lévesque, Rouleau, & Renaud, 2018; Renaud et al., 2013; Trottier et al., 2014). In the context of victimization, Loranger and Bouchard (2017) validated a virtual environment to safely expose sexual abuse victims to a sexual assault scenario, and a later study (Loucks et al., 2019) reported the efficacy of a VR exposure-based treatment for lasting reduction of posttraumatic stress symptoms in adult victims of sexual assault. In sum, the relevance and efficacy of VR for several mental disorders is strongly supported, but evidence remains scarce or emerging for sexual dysfunctions and other sexual difficulties, and no evidence-based treatment (e.g., virtual reality exposure-based therapy) has been thoroughly evaluated for SA.

Despite the paucity of studies, VR could yield several benefits for the assessment and treatment of SA. Firstly, VR can provide conditions that closely resemble the ecological properties of real-life circumstances (Trottier et al., 2019). This is critical given that specific environmental conditions must be present for the occurrence of SA responses. This advantage could increase the accuracy with which clinicians and researchers measure the severity of symptoms associated with SA. Unlike the conventional use of self-report questionnaires or clinical interviews where individuals are asked how they would behave based on a written or verbal description of a specific situation (Huang & Bailenson, 2019), VR allows the person to be immersed in a virtual environment that replicates the conditions associated with manifestations of SA, and then to measure their actions, experiences, and reactions in real time. In this regard, using 3D immersive VR environment over 2D videos could increase presence and attentional involvement, leading to emotional responses ecologically more representative of reactions that would be experienced in the physical world. Previous studies suggested that, compared to 2D explicit videos on a computer monitor, the presentation of sexual stimuli in VR yield a stronger effect on physiological and subjective sexual arousal (Milani et al., 2021; Simon & Greitemeyer, 2019) and presence (Fromberger, Meyer, Kempf, Jordan, & Müller, 2015; Milani et al., 2021; Simon & Greitemeyer, 2019). Secondly, the use of synthetic characters in VR treatment could allow to progressively simulate situations that are often avoided by people with SA and that are therefore largely absent from their lives (e.g., romantic and erotic interactions; Borg, Both, ter Kuile, & de Jong, 2020). Thirdly, situations related to stress and fear in SA (e.g., sexual assault, sexual failure, rejection, feeling trapped in a sexual interaction) cannot really happen in a virtual environment. Thus, individuals with SA could freely explore and experience new sexual behaviors in a safe and controlled virtual setting. Fourthly, the literature on SA treatment focuses on the use of different cognitive-behavioral interventions (Borg, Both, ter Kuile, & de Jong, 2020), including imaginal exposure (i.e., when exposure is carried out by mental imagery, under relaxation; Janata & Kingsberg, 2005). As the therapist can never be assured that their clients are truly or continuously exposing themselves in thoughts (Baus & Bouchard, 2014), VR could offer higher controllability of exposure to the aversive sexual stimuli, limiting possibilities of experiential avoidance compared to classical imaginal exposure. Finally, virtual scenarios occur in a controlled setting, and can therefore be identical over multiple clinical exposures (Clay, König, & Koenig, 2019), and can also be paused or repeated at any time and as often as is deemed necessary for an efficient extinction of the fear response (Baus & Bouchard, 2014).

In summary, while there is a growing body of studies and increasing public interest for technological advancements in the field of human sexuality (teledildonics, erobotics, VR pornography; Dubé & Anctil, 2020), research on VR applications in sex therapy is critically lacking (Lafortune et al., 2020; Twist & McArthur, 2020). VR might be a promising approach for the treatment of SA; however, standardized treatment protocols (hardware and software) have yet to be validated. Therefore, it remains to be examined whether VR could represent a valid tool to assist future exposure-based treatment for SA.

Aims of the present study

This study aimed to examine the capacity of a virtual environment to safely trigger the typical emotional responses of SA in individuals reporting low versus high levels of SA, during the exposure to six virtual scenarios in which the intensity of the sexual stimuli progressively increases. Subjective emotional responses (anxiety and disgust), psychophysiological measures of sympathetic nervous system activity (skin conductance, heart rate, and cardiac output), as well as visual avoidance (using eye-tracking) were assessed throughout the virtual exposure. The following hypotheses were formulated:

H_1. Among high-SA individuals, anxiety, disgust, physiological activity, and visual avoidance triggered by the virtual environment would gradually increase from one scenario to the next in tandem with the sexual stimuli's progressively increasing intensity;

H_2. Individuals with high-SA would display more anxiety, disgust, physiological activity, and visual avoidance than low-SA individuals.

Result will inform on the potential relevance of using VR in the development of future exposure-based therapy for SA.

Method

Participants

Thirty-nine individuals participated in this study and were allocated into low- ($n = 16$) or high-SA ($n = 23$) groups. Mean age was 29.9 years ($SD = 11.31$). The sample was mostly comprised of women (> 60%), with 17% of participants identifying as men and 21.5% as non-binary. Sociodemographic characteristics of the sample are presented in Table 1.

Participants were recruited from a bank of respondents who had previously participated in another SA study (Lafortune, Canivet, Boislard, Godbout, 2021) and through advertisements on social media (*Facebook* and *Instagram*). Eligibility criteria were: (a) to report either elevated (high-SA group) or low (low-SA group) levels of SA (see *Measures*

Table 1 Sociodemographic characteristics of participants.

	Low-AS			High-AS		
	M	SD	%	M	SD	%
Age	28.75	11.76		33.22	17.5	
Gender						
Male			31.3			4.3
Female			43.8			73.9
Non-binary			25.1			21.5
Sexual orientation						
Heterosexual			50			47.8
Homosexual			6.3			4.3
Bisexual/pansexual			25.1			21.7
Other (e.g., questioning)			18.8			26
SAS-BF total score	156.25	66.92		1011.52	283.70	

section for details); (b) to be over 18 years old; (c) to have sufficient knowledge of French to complete the questionnaires.

The exclusion criteria were as follows:

- taking psychoactive substances on the day of the immersion;
- reporting untreated Attention Deficit/Hyperactivity Disorder.

Measures

Sexual Anxiety Scale—Brief form (SAS-BF)

The French version of the SAS-BF (Lafortune, Canivet, Boislard, & Godbout, 2021) was used in this study as a primary criterion to assess and determine the presence of either low- or high-SA. The SAS-BF is a 16-item scale derived from the 56-item *Sexual Anxiety Scale* (Fallis, Gordon, & Purdon, 2011), measuring levels of discomfort and anxiety experienced in a broad range of socio-sexual contexts (e.g., sexual communication, solitary and partnered sexual activity, sexual information, sexual fantasies, etc.). Participants rated their degree of anxiety using a list of sexually relevant situations or stimuli on an 11-point Likert scale ranging from 0 (*extremely comfortable/pleasurable*) to 100 (*extremely discomforting*). The SAS-BF includes items such as ''*Talking with my partner about our respective sexual fantasies*'' or ''*Exploring erogenous, or sexually exciting, parts of my body when I am alone*''. This scale yielded strong psychometric properties in terms of factor structure and reliability in a previous study ($\alpha = .90$; Lafortune, Canivet, Boislard, & Godbout, 2021), and was chosen over other scales assessing anxious or phobic responses to sexual cues (e.g., Janda and O'Grady, 1980; Katz, Gipson, & Turner, 1989) because the latter appeared to be relatively outdated considering contemporary socio-cultural shifts (e.g., attitudes towards premarital sex; Janda & O'Grady, 1980) or conjointly assessed SA along with other constructs, such as attitudes towards homosexuality (Fisher et al., 1988). The mean SAS-BF score ($M = 534$) and standard deviation ($SD = 281$) found in a previous study among the general population (Lafortune, Canivet, Boislard, & Godbout, 2021) were used in the present study to identify and assign participants to low vs. high-SA groups. Participants scoring one *SD* or more above the SAS-BF mean comprised the ''high-SA'' group (i.e., score above 815). Those scoring one *SD* or more below the mean formed the ''low-SA'' group (i.e., score below 253).

Fear and disgust ratings

The Subjective Units of Discomfort Scale (SUDS; Wolpe, 1990) is a single-item self-report distress measure. Throughout the experiment, participants were asked to rate their anxiety and disgust on a scale of 0 — *Totally calm/not disgusted at all* to 10 — *Unbearable anxiety/disgust*. Precisely, participants rated their discomfort during a ten-second period (1) before exposure (baseline) and (2) at the end of each of the six exposure levels, during which no stimuli were presented, and the screen was blue. SUDS is widely used to measure emotional responses in research settings aiming to determine the validity of virtual environment for mental disorders (e.g., Owens & Beidel, 2015; Reger et al., 2019; Takac et al., 2019).

Psychophysiological measures

Psychophysiological measures included skin conductance level (SCL), heart rate (HR), and cardiac output (CO). Signals were recorded using BIOPAC MP150 with ECG100C, EDA100C and NICO100D amplifiers. A sample rate was set at 1000 Hz. Channel data were simultaneously recorded through the Acqknowledge software (Biopac Systems). The physiological data were continuously transmitted and recorded wirelessly during a 2-minute base-level measuring period (i.e., during the second half of the first relaxation exercise) and throughout the VR simulation. Although data were recorded without interruption, the psychophysiological data were separated and analyzed at specific time intervals: during baseline and during the six stages of the experimental scenario. Skin conductance levels (SCL) measure the electrical conductivity of the skin as an index of sympathetic responses with two Ag/AgCl electrodes placed on the second phalanx of the index and middle fingers of participants' non-dominant hand. HR was obtained by an electrocardiogram (ECG) with three disposable pregelled Ag/AgCl electrodes placed on the chest in a lead II configuration (Blascovich, Vanman, Mendes, & Dickerson, 2011). A band pass was applied to filter the data that did not range within 0.5—35 Hz. Beats per minute were analyzed by the Acqknowledge program, which detected the number of QRS-peaks per minute by discerning the interval between heartbeats. HR was then derived from the waveform. Impedance cardiography was employed to measure CO. Four electrodes were placed around the neck and four others were placed on the side of the thorax (see Sherwood et al., 1990). A low pass was applied to filter the data under 50 Hz. The dz/dt data was then derived from the raw Z scores and an artifact removal was performed with the Acqknowledge software. Lastly, an impedance cardiography analysis was executed to retrieve CO from the mean dz/dt scores.

Eye-tracking

Eye-tracking (i.e., fixation time, gaze location) was chosen as a relevant approach to assess the attentional avoidance of sexual stimuli during virtual exposure. Two studies using VR (Fromberger et al., 2015; Renaud, Rouleau, Granger, Barsetti, & Bouchard, 2002) have documented strong relationships between viewing time, gaze behaviors, and sexual preferences. Specifically, Fromberger et al. (2015) showed that participants gaze significantly longer at sexually attractive characters than unattractive ones (i.e., in line with their sexual orientation). Furthermore, in their research examining the use of VR to treat social anxiety, Dechant, Trimpl, Wolff, Mühlberger, and Shiban (2017) and Singh, Capozzoli, Dodd, and Hope (2015) both found that high-socially-anxious individuals stared at facial areas for a significantly shorter amount of time than low-socially-anxious individuals. Examining fixation time among individuals with SA could thus bring insight regarding their predicted tendency to avoid paying attention to sexual stimuli. For the current study, eye movement was measured using the FOVE infrared eye-tracking VR headset (https://fove-inc.com/) to assess gaze behavior and visual contact avoidance in each virtual scene. We also used Unity and the FOVE Data Collector Plug-in to record gaze numeric values asynchronously and to ensure a fluid rendering of the virtual scenes, while keeping a high volume of granular data. To obtain reliable and valid data for gaze behavior, six areas of interest (Clay et al., 2019) covering the visual field were determined: (1) the face; (2) the chest; (3) genitals; (4) hands; (5) feet; (6) the rest of the virtual environment.

These areas were recognized by the software through the use of a virtual mouse cursor following the user's gaze center point, of which the hovering coordinates were compared in real-time with the surfaces and assets from the virtual scenes. Eye fixation on these areas of interest were defined as a period of at least 100 milliseconds during which the gaze focused on the same zone (Alexander & Charles, 2009). Visual attention was defined as the total viewing time on the areas of interest, for each separate scene.

VR system

The experimental scenario was designed for the purpose of the present study using Unity software, and assets (e.g., characters, clothes, body fluids) were selected from Daz 3D, Unity, and specialized websites for photorealistic body parts (e.g., genitals; https://www.renderotica.com/). The virtual scenario was developed based on: (a) characteristics of virtual environments used in related disorders or experiences (e.g., social anxiety, sexual assault; Bouchard et al., 2017; Dechant et al., 2017; Loranger & Bouchard, 2017); (b) documented anxiety/disgust-provoking sexual situations or behaviors characteristic of SA (Borg, Both, ter Kuile, & de Jong, 2020; Brotto, 2010) such as nudity, signs of sexual interest (lengthy eye contact, approach behaviors), arousal, and orgasm (e.g., erection, body fluids, vocalizing); (c) the evaluation of the research team (i.e., three experts in clinical sexology).

The virtual environment consisted of a virtual room (living room) in which participants were successively exposed to six scenarios in which a virtual character (''female'' or ''male'') showed erotic behaviors of increasing intensity: two low level exposure scenarios (e.g., the character is fully clothed, drinking, some eye contact), two moderate level scenarios (e.g., partially naked, beckoning the participant to come closer), and two high level scenarios (e.g., naked, caressing their genitals, masturbating, and ejaculating/reaching orgasm) (Fig. 1). During exposure, audio stimuli ranged from soft breathing to moaning in order to enhance a state of presence (Hendrix & Barfield, 1996; Slater, 2018) and emotional responses (Riva et al., 2007) consistent with the intended level of exposure. Both the ''female'' and ''male'' scenarios followed an equivalent sequence in terms of displayed behaviors (e.g., length and number of visual contacts, invitations, sexual behaviors). The choice of scenario (with the ''female'' or ''male'' character) was determined before the experiment according to the participant's self-reported sexual orientation or based on their expressed preference (e.g., for bisexual individuals). The virtual immersion also included a four-minute relaxation exercise (inspired from the *Heart-Focused Breathing* technique; McCraty & Zayas, 2014), before and after exposure to the six scenarios. This exercise helped to establish a baseline for psychophysiological arousal assessment, familiarizing participants with VR before the experiment (Fig. 1), and fostering post-exposure relaxation.

Procedure

Participants who were interested in the study were invited to review and electronically sign the informed consent form and to complete a short questionnaire (e.g., SAS-BF) to confirm that they met the inclusion criteria and to assign them to one of the two groups (i.e., low- or high-SA). Participants were then contacted by phone or email to be provided with information regarding the study procedure and to schedule an appointment for the 50-minute experiment. Once in the laboratory, the investigator set up and adjusted the equipment (i.e., electrodes for HR, SCL, and CO measurements, head-mounted display, headphones). During the immersion, participants were instructed to remain stationary (motion in the virtual environment was limited to the head) to reduce possible cybersickness (Clay et al., 2019; Davis, Nesbitt, & Nalivaiko, 2014) and avoid the disruption of the electrophysiological signals.

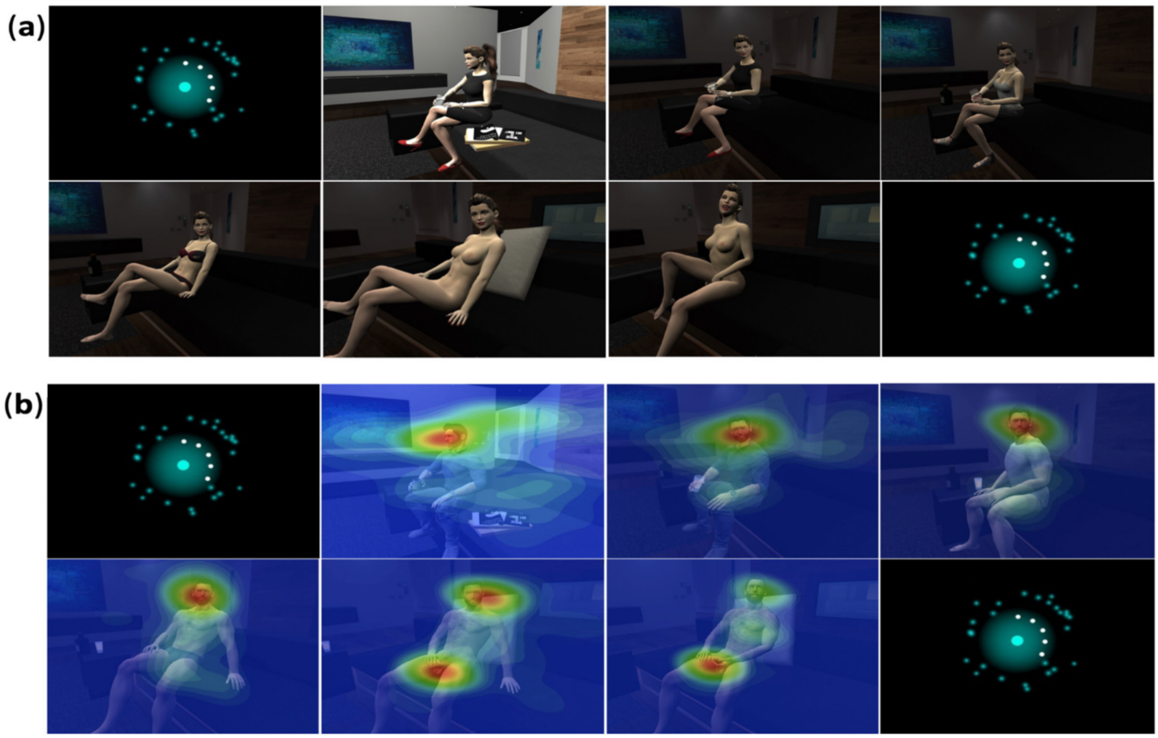

Figure 1 (a) Progressive stages of the experimental scenario (from left to right): (Pre) relaxation; (1) the character is fully clothed (without eye contact); (2) still dressed, first eye contacts and smiles towards the participant; (3) partially naked, eye contacts last longer, spreads his/her legs towards the participant; (4) in underwear, legs spread, he/she invites the participant to come closer; (5) naked, invites to get closer and caresses gently him/her legs and genital area; (6) masturbates until he/she reaches orgasm; (Post) relaxation. (b) Materialization of eye-tracking data as a map showing the zones swept by the gaze behaviors as well as the lapse of time eye contact lasted for each scenario, using the Unity customizable 360 Heatmap software.

A trained research assistant was present as a ''computer technician'' to run the application, address technical problems, collect subjective emotional responses (SUDS), and provide care as needed (e.g., distress or other serious emotional response). The VR application used the Unity software and was fully automated once started (duration: 18 min. 28 s). Once the FOVE headset was installed, participants were asked to stare at a target point on the screen for eye-tracking calibration. Then, participants were immersed in a virtual environment designed to complete a relaxation exercise (Fig. 1). At the end of the exercise, participants were asked to report their level of fear and disgust (SUDS) to assess the baseline. Following the relaxation exercise, the six scenarios began (levels of exposure), and a blue screen appeared for ten seconds at the end of each scenario. During these blue screen pauses, participants were asked to rate their level of fear and disgust (SUDS). The investigator continuously monitored the participants' SUDS scores as an indicator of their discomfort or distress. Participants who reached 7 or more on the 10-point SUDS were asked if they felt comfortable pursuing the experiment. No participant decided to pause or terminate the experiment before the end of the immersion. After the presentation of the six scenarios, participants completed a second relaxation exercise to help them regain their emotional baseline. Once the study was completed, the investigator proposed a debriefing period to the participants regarding their immersion experience and its effect on their emotional state. The participants received gift-cards ($20 CAD) after completing the experiment. This study was approved by the University's Institutional Ethics Review Board.

Data analysis

ECG, SCL, and CO data were pre-processed with the AcqKnowledge software. For HR, beats per minute (bpm) were analyzed; for SCL, mean skin conductance level (SCL, in μS) was calculated; and for CO, liters per minute (L/min) were measured. The following intervals were considered for SCL, HR, and CO: the baseline (the 2 last minutes of the first relaxation exercise) and the total duration of each six scenarios (excluding the blue screen periods when participants gave their fear ratings). For eye-tracking, raw data from the eye-tracking system came in the form of zone numbers followed by gaze duration. Following the automated cleaning of artefacts and anomalies, gaze duration data was separated by scenario and zone. Total fixation time for three different zones was assessed (Zone 1 = facial area; Zone 2 = combination of chest, abdomen and pelvic areas; Zone 3 = combination of legs, arms, and surrounding environment) and percentage of fixation time per scenario were estimated.

All statistical analyses were performed on SPSS, version 26. Repeated measures analyses of variance (ANOVAs) for the high-SA group to compare SUDS, SCL, HR, CO, and

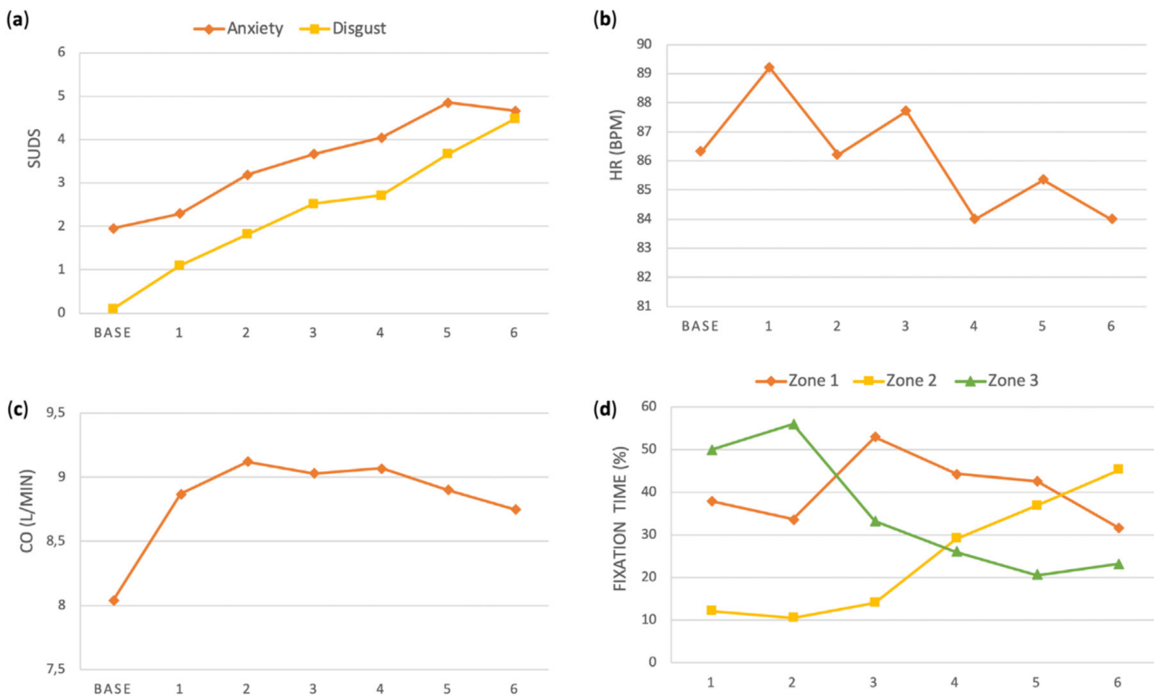

Figure 2 Illustration of SUDS scores (a), HR (b), CO (c), and fixation time for each zone (d) based on the order of presentation of the 6 increasing intensity scenarios, following baseline. Estimated marginal means.

fixation time over the seven time points (baseline and after each scenario). Repeated measures ANOVAs were also performed to compare the two groups (low- vs. high-SA) across the seven time points on the same subjective and physiological outcomes. As Mauchly's Test of Sphericity suggested violation of the sphericity assumption, the Greenhouse-Geisser correction was applied to all estimated effects, except for fixation time of Zones 1 and 3 (Huynh-Feldt). Pairwise and polynomial contrasts were conducted to examine significant main effects. Lastly, paired and independent sample *t*-tests were performed to examine within- and between-group differences. The purpose of these analyses was to: (a) verify whether anxiety, disgust, physiological activity, and visual avoidance increased among high-SA individuals during immersion from one scenario to the next (i.e., in tandem with increased sexual stimuli; H_1); (b) to assess whether high-SA participants experienced more anxiety, disgust, physiological activation, and visual avoidance compared to low-SA individuals (H_2).

No participant dropped out of the study, but artefacts and measurement failures, particularly for eye-tracking (12.8%), resulted in physiological data not being available from all participants. Missing data were omitted from the analyses.

Results

For SUDS scores, repeated-measures ANOVAs showed a main significant large effect across all six scenarios for anxiety, $F(3.82, 56.37) = 17.25$, $p < .001$, $\eta_p^2 = .46$, and disgust $F(2.7, 54.01) = 27.58$, $p < .001$, $\eta_p^2 = .58$. Polynomial contrasts indicated that the linear component of the effect of time was significant for both anxiety, $F(1, 20) = 41.54$; $p < .001$, and disgust, $F(1, 20) = 54.36$; $p < .001$. This finding suggests that SUDs tend to increase as the levels of exposure increase, from baseline to scenario 6 (see Fig. 2). Results from repeated pairwise-contrast analyses between levels of exposure for SUDS scores and physiological outcomes are presented in Table 2.

Regarding physiological responses, analyses did not show a significant effect for time on SCL, but a notable trend was observed for HR, $F(2.05, 45.1) = 2.48$, $p = .09$, $\eta_p^2 = .10$, with a medium effect size. Polynomial contrasts indicated that HR decreased linearly overall as the experiment progressed, $F(1, 22) = 8.94$; $p = .007$. Estimated marginal means (Fig. 2) show that HR increased when exposure levels changed from low (scenario 1) to moderate (scenario 3), and to high-intensity (scenario 5). Regarding CO, analyses indicated a significant large effect for time, $F(2.17, 47.69) = 4.84$, $p = .01$, $\eta_p^2 = .18$. Polynomial contrasts indicated significant quadratic, $F(1, 22) = 20.39$; $p < .001$, and cubic, $F(1, 22) = 8.13$ $p = .009$, effects, meaning that CO did not increase linearly (i.e., as the exposure scenario progressed), but instead reached a peak at scenario 2, to decrease thereafter (see Fig. 2).

For eye fixation duration, analyses indicated a significant main large effect across the six scenarios for Zone 1 (i.e., facial area), $F(4.69, 79.74) = 12.24$, $p < .001$, $\eta_p^2 = .42$, Zone 2 (i.e., chest, abdomen and pelvic areas), $F(1.97, 33.44) = 39.19$, $p < .001$, $\eta_p^2 = .70$, and Zone 3 (i.e., surrounding environment, legs, arms), $F(4.9, 83.22) = 39.07$, $p < .001$, $\eta_p^2 = .70$. For Zone 1 fixation, significant quadratic, $F(1, 17) = 22.68$, $p < .001$, and cubic, $F(1, 17) = 4.32$, $p = .05$, polynomial trends were found, but the linear component of the effect of time was not significant. These results suggest that fixation on the facial area reaches its peak at scenario 3 (i.e., when the character is gazing more at the participant), and then decreases (i.e., as the character is progressively

Table 2 Pairwise differences of the SUDs and physiological outcomes between each scene (high-SA group).

	Baseline vs. SC1		SC1 vs. SC2		SC2 vs. SC3		SC3 vs. SC4		SC4 vs. SC5		SC5 vs. SC6	
	F	η_p^2	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2
Disgust	9.07**	.16	17.41***	.27	27.96***	.37	25.63***	.35	35.54***	.40	51.62**	.52
Anxiety	1.83	.04	20.08***	.30	25.50**	.35	29.70***	.38	50.55***	.51	34.78***	.42
HR	3.21	.06	5.39*	.11	.07	.00	1.61	.03	4.36*	.08	9.02**	.14
CO	15.99***	.44	11.78**	.35	2.96	.12	2.01	.09	.15	.01	.21	.01
Zone 1	–	–	2.09	.11	33.89***	.67	2.83	.14	.02	.00	13.17**	.44
Zone 2	–	–	3.93	.19	51.25***	.75	59.00***	.78	53.35***	.76	23.63**	.58
Zone 3	–	–	2.63	.09	7.20*	.30	24.49***	.59	34.31***	.67	70.05**	.81

* $p < .05$.
** $p < .01$.
*** $p < .001$.

unclothed and shows increased sexual arousal). Polynomial contrasts showed that the linear component of the effect of time was significant for Zone 2, $F(1, 17) = 63.2$, $p < .001$, indicating that the fixation time on the chest, abdomen and pelvic areas increased for high-SA individuals as the level of exposure to sexual stimuli increased. Conversely, a linear trend was found for Zone 3 ($F(1, 17) = 94.00$, $p < .001$), suggesting that attention to the surrounding environment and less-sexualized body parts (e.g., feet) decreased as the level of exposure to sexual stimuli increased (see Fig. 2).

Repeated-measures ANOVAs comparing low- and high-SA groups across the seven time points showed significant moderate group*time interactions for both anxiety, $F(2.94, 102.71) = 2.66$, $p = .05$, $\eta_p^2 = .07$, and disgust, $F(2.5, 87.51) = 5.1$, $p = .005$, $\eta_p^2 = .13$, indicating that the high-SA group experienced more anxiety and disgust than the low-SA group during each of the six scenarios (Fig. 3). As shown in Fig. 3, *t*-tests revealed that, compared to baseline, both groups showed significantly higher scores at scenario 6 for both anxiety ($t = -3.15$, $p = 0.007$, $d = .92$; $t = -5.54$, $p < 0.001$, $d = 1.45$, respectively) and disgust ($t = -2.99$, $p = 0.009$; $t = -7.92$, $d = .99$, $p < 0.001$, $d = 2.4$, respectively). Although, the analyses showed that the degree of increase was significantly higher in the high-SA group than in the low-SA group for both anxiety ($t = -2.05$, $p = .048$, $d = .68$) and disgust ($t = -3.21$, $p = 0.003$, $d = 1.46$).

No significant group*time interactions were found for SCL, HR, and CO. Furthermore, no significant group*time interactions were found for eye fixation duration, regardless of the zone.

Discussion

The aim of this study was to examine the ability of a virtual environment to safely elicit typical SA emotional responses and to determine whether it might be adequate in future virtual reality exposure-based treatments for this condition. The following points discuss the main outcomes related to SUDS, physiological responses, and gaze fixation.

Both hypotheses regarding SUDS were supported. Firstly, results suggested that the progressive increase in the intensity of sexual stimuli throughout the virtual scenarios was accompanied by increased anxiety and disgust among high-SA participants. Secondly, high-SA individuals reported more anxiety and disgust than low-SA individuals as the levels of exposure increased. Group differences were particularly large for disgust. The increase in SUDS also observed in the low-SA group may not be surprising given the nature of the study and stimuli. More precisely, this trend in anxiety and disgust responses may be due to: (a) social desirability, as participants may have perceived that the research team expected them to experience anxiety in the virtual world (recruitment advertisements mentioned that the study was about SA); (b) the discomfort reported by some participants about being monitored by the research assistant while watching sexual content; (c) the fact that the virtual simulation might have been perceived as coercive (i.e., with no ability to move, being alone in an enclosed space with a virtual character that progressively demonstrated non-consensual sexualized behaviors); (d) the *uncanny valley* phenomenon, whereby human-looking entities (e.g., virtual humanoid agents, robots) can be perceived as eerie or creepy, resulting in an activation of the fear and disgust systems (e.g., Ho & Dautenhahn, 2008; MacDorman & Entezari, 2015; Palomäki et al., 2018).

High-SA participants' physiological responses are only partially aligned with their subjective responses, as SCL activation was not significant. Yet, CO and HR outcomes suggested an activation of the sympathetic nervous system in response to the virtual environment. More precisely, CO results showed an initial activation from baseline to scenario 2, followed by a gradual decrease in reactivity from scenario 2 until the end of the immersion. HR emulates a similar trend, characterised by an increase at scenario 1, followed by a decrease in activation until the end of the simulation. Nevertheless, throughout the decrease of HR, participants seemed to have reacted to scenarios 1, 3, and 5 more strongly than the subsequent ones. It should be noted that these three specific scripts (i.e., scenarios 1, 3, and 5) were each intentionally designed to be more sexually explicit than the previous one, as they marked a change in the intensity of sexual stimuli from low in scenarios 1 and 2, to moderate in scenarios 3 and 4, to high in scenarios 5 and 6. These trends are consistent with typical patterns of sympathetic system activation in fear-inducing contexts, for both CO and HR (Kreibig, Wilhelm, Roth, & Gross, 2007; Lang, Melamed, & Hart, 1970; Lovallo, 2015; Wieser, Pauli, Alpers,

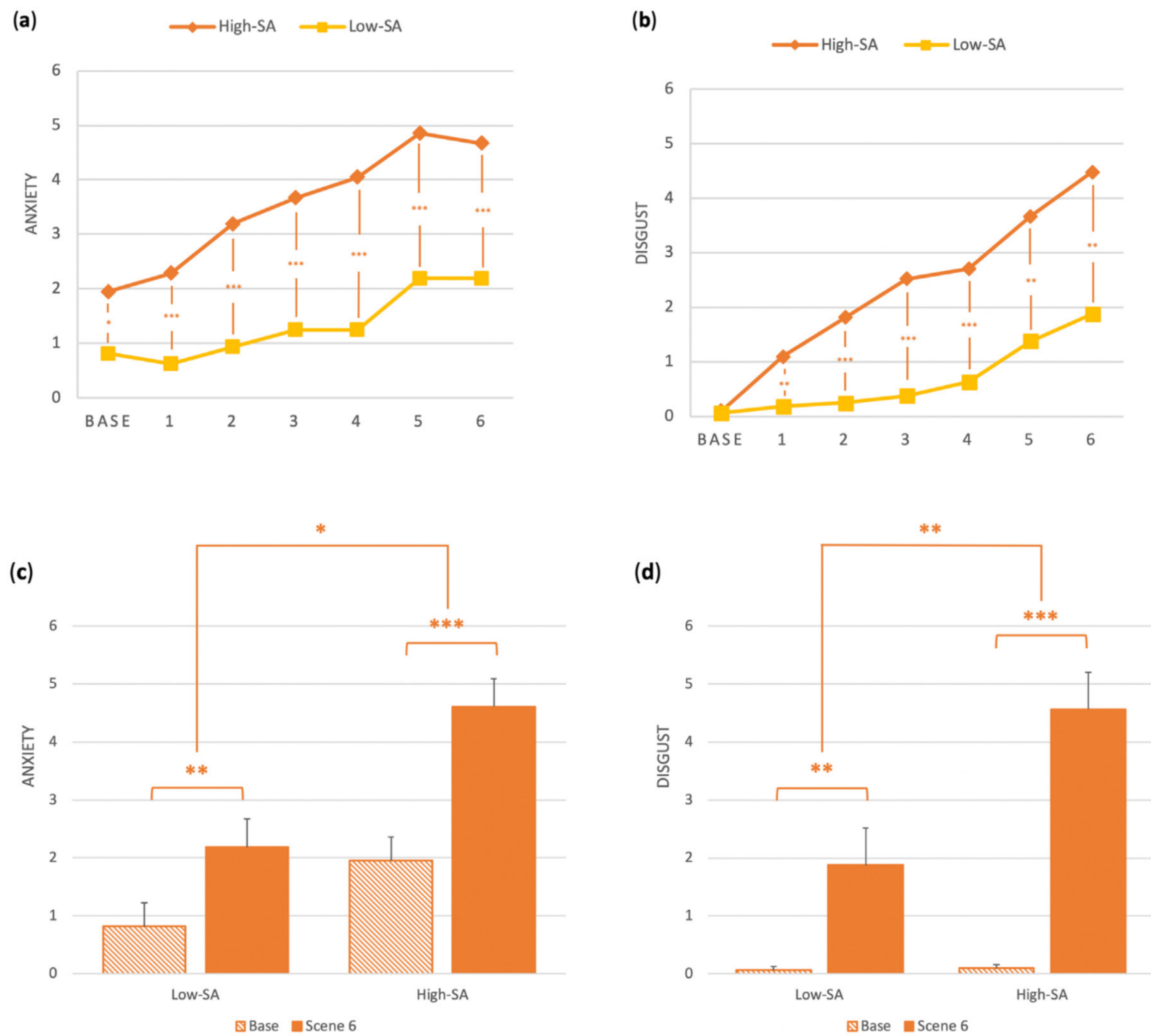

Figure 3 Estimated marginal means and differences for anxiety (a) and disgust (b) for the low- and high-SA groups, based on the order of presentation of the 6 exposure scenarios. Significant changes of the SUDS scores for anxiety (c) and disgust (d) in the low- and high-AS between Baseline and Scene 6 (between- and within-groups). $*p < 0.05$; $**p < 0.01$; $***p < 0.001$ (two-tailed).

& Mühlberger, 2009), reflecting a plausible initial fight or flight response when faced with a new, potential threat. Consistently with our data, the subsequent decreases in CO and HR might reflect a conservation-withdrawal response, aiming at reattaining a state of homeostasis after experiencing emotional reactivity (Kreibig et al., 2007). Furthermore, as CO responses vary according to HR, it is logical that both measures follow the same trends (Vincent, 2008). The psychophysiological data did not confirm our second hypothesis, as it did not differentiate low- and high-SA participants in terms of activation. The failure to detect these differences could be due to a low statistical power, given the relatively low sample size. Another plausible explanation is the relative inability of these measures to discriminate fear from other responses, such as sexual arousal, as the two activate the sympathetic nervous system (Grimshaw & Philipp, 2021; Zuckerman, 1971). Future studies would benefit from using other psychophysiological measures (e.g., quantitative electroencephalography, thermography, plethysmography) to discriminate fear and disgust from other physiological responses (e.g., sexual arousal).

Contrary to expectations, analyses of fixation time showed significant effect, but not in the hypothesized direction (particularly for Zones 1 and 2). For instance, fixation duration on the chest, abdomen and pelvic areas (Zone 2) increased for high-SA individuals as the level of exposure progressed. Furthermore, the estimated mean differences of visual fixation for each zone suggest that low- and high-SA groups share similar patterns in terms of visual attention across levels of exposure. This finding is partly consistent with those of previous studies using eye-tracking in SA-related clinical conditions involving fear in interpersonal settings (e.g., social anxiety). If Dechant et al. (2017) and Singh et al. (2015) found that highly socially anxious individuals fixated facial areas for significantly shorter lengths of time than their low social anxiety counterparts, Wieser et al. (2009) reported that women high in social anxiety tend to pay greater attention to the eye area than those who are low in social anxiety. Similarly, Reichenberger, Pfaller, and Mühlberger (2020) found that socially anxious individuals were more likely to initially direct their attention toward virtual agents paired with aversive stimuli (e.g., verbal rejection) than when in a non-aversive condition. The same authors suggested that socially anxious individuals tend to initially guide their attention to emotionally threatening information as a sign of hypervigilance (Reichenberger et al., 2020). In the present study, increased fixation time on sexual or interaction cues (e.g., genitals, face) from scenarios 1 to 6 may as well reflect the maintenance of a state of alertness regarding potential threats (e.g., aggression, sexual coercion, loss of control over the sexual situation) associated with the visible sexual interest and arousal depicted by the virtual character. Other underlying mechanisms might also explain this pattern. For instance, the stimulus-driven effect (Imhoff, Schmidt, Weiß, Young, & Banse, 2012) posits that the higher the sexual salience of a stimulus, the longer the viewing time. Another hypothesis is that SA is not necessarily a reflection of a lack of sexual interest or of low sexual desire, although they are sometimes related (Basson, 2010; Brotto, 2010; Kaplan, Klein, & Klein, 1987). In summary, results indicate that eye-tracking may not be a good discriminating measure to assess the level of avoidance in SA. Yet, the fact that no visual avoidance was found could represent a strength for future exposure-based treatment using this virtual environment, as behavioral and cognitive avoidance prevent the activation of the fear structure (Foa and Kozak, 1986; McNally, 2007) and hinder the extinction learning process (Craske, Treanor, Conway, Zbozinek, & Vervliet, 2014).

Research and clinical implications

First, this VR application appears safe, since no adverse events were reported, and because even high-intensity scenarios (5 and 6) were associated with, on average, tolerable levels of distress in terms of anxiety and disgust ($M_{SUDS} \sim 5$). These levels may be, in this respect, deemed appropriate targets during therapeutic exposure sessions to modify the magnitude of aversive experiences. According to *Emotional Processing Theory* (Foa & Kozak, 1986), effective exposure involves an optimal level of activation of the fear network; too little activation of the fear response system (i.e., underengagement) or too much activation (i.e., overengagement) can indeed hinder emotional and informational processing linked to the efficacy of exposure-based treatment (Rauch & Foa, 2006). Hence, further research is needed to explore whether, and to what extent, the anxiety-triggering sexual stimuli in the virtual scenario match elements of high SA individuals' fear network (i.e., facilitating the emergence of representations or autobiographical memories related to the conditioned aversive response), which is a prerequisite to ensure the modification of fear-inducing pathological associations (Foa & Kozak, 1986; McNally, 2007). However, the applicability of *Emotional Processing Theory* on disgust responses has been understudied (McNally, 2002; Olatunji et al., 2009). Also, a number of experiments involving exposure to fear/disgust-provoking stimuli among phobic individuals (e.g., spiders, hypodermic syringe, contamination; McKay, 2006; Olatunji et al., 2009; Olatunji, Huijding, de Jong, & Smits, 2011; Preusser, Margraf, & Zlomuzica, 2017; Smits, Telch, & Randall, 2002) suggest that disgust is not reduced by exposure as efficiently as fear. Since no data are available regarding the decrease of disgust following *in virtuo* exposure to sexual stimuli, future virtual exposure-based treatment studies should examine the respective influence of changes in levels of fear and disgust on SA. Moreover, future virtual environments for SA should include more diverse anxiety/disgust-triggering cues in their design to reflect the variability in sexual contexts commonly associated with SA (e.g., attempted assault, rejection, sexual intercourse, sexual communication, etc.). To enhance the level of realism of the virtual environment, future studies could include the ability to move one's body and engage interactively with the virtual characters. Applications of VR in sex therapy will be profoundly shaped by advancements in artificial intelligence. Hence, using erobots (artificial erotic agents; Dubé & Anctil, 2020) in virtual interactive environments simulating realistic romantic and erotic encounters could be used to develop sexual skills, explore sexual preferences and get reacquainted with one's body and sexuality for sexually aversive people. Furthermore, a gradual rise in anxiety up to scenario 5 followed by a slight but significant decrease at scenario 6 among high-SA participants suggest that participants might have become habituated to the virtual scenario around scenario 5 (as indicated by CD and HR outcomes). Additional research is needed to determine whether such habituation is maintained even with higher levels of exposure to the virtual environment, and whether a similar pattern if found for disgust. In future studies on VR-based intervention for SA, examining changes in physiological arousal may allow to track progress between pre- vs. post-intervention and identify best physiological measures to assess recovery in therapy (Chen & Daigle, 2021). Previous research has indeed revealed significant changes on different physiological measures (e.g., HR, SCL) after exposure-based therapy (Yang, Mady, & Linnaranta, 2021). Finally, this virtual environment presents several advantages for future research and clinical applications as it (a) is fully immersive (i.e., three-dimensional animations and sounds); (b) is compatible with any affordable head-mounted display compatible with the Unity system; (c) provides conditions for an ''ethical'' exposure to sexual material in a safe and controlled environment; and (d) allows each scene to be paused, selected, or repeated as long as needed in therapy, in a hierarchical-linear fashion (i.e., habituationbased model; Foa & Kozak, 1986) or in a variable exposure perspective for deepened extinction (i.e., inhibitory learning model; Craske et al., 2014).

Limitations

The present findings should be considered in light of its limitations. First, the study involved a relatively small sample size, which might have compromised the generalizability of findings. In addition, the high-SA group mainly included women and non-binary individuals. Regardless of the diversity of our sample (i.e., gender and sexual orientation), the small number of men does not reflect the prevalence of SA in the general population (Kedde, 2012). The high number of non-binary individuals in our study could also represent a sampling bias. It is, however, worth mentioning that few VR studies explicitly included non-binary individuals, let alone asked participants if they identified as a gender situated outside of the gender binarity. The small sample size also prevented us from statistically controlling for potential differences between the immersion experiences with the female and the male character, which hindered our ability to examine if both scenarios offer the same efficacy in eliciting typical SA emotional responses. Future studies should be conducted to test possible differences between these two conditions. Secondly, this study did not include, nor control for, simulations of a broad range of contexts typically related to SA etiology (e.g., sexual assault) or conditions where SA usually manifests (e.g., one's own nudity or masturbation, sexual intercourse). Therefore, some people suffering from SA may have reacted differently if individualized ecological conditions related to their disorder were elicited in the virtual environment. Thirdly, considering the aim of this study, highly sexually avoidant individuals may be underrepresented in the present sample, thus affecting the findings' generalizability for this sub-population. Lastly, statistical treatment of the data did not examine the effect of each scene independently without the joint effect of the previous stimuli.

Conclusion

Given the impact of SA on sexual and relational well-being and the advantages of virtual reality exposure-based therapy over traditional treatment (e.g., *in vivo* exposure), VR might represent a promising approach for the treatment of SA. The present study's findings support this new virtual environment's validity and safety relative to progressively eliciting typical SA emotional responses. This validation study should be followed up with treatment validation studies to test its efficacy as part of a virtual reality exposure-based treatment to alleviate distress in people living with SA.

Disclosure of interest

The authors declare that they have no competing interest.

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