Investigating Female Sexual Presence Through Triangulation of Behavioral and Physiological Measures in Virtual Reality: Towards Therapeutic Applications for Sexual Disorders

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Abstract: Exposure to sexual contexts by means of immersive, extended reality technologies, offer an opportunity to both: better understand sexual responding, and in turn, offers insights as to how the same technology could help in treating sexual disorders. The present papers reports on the ability of behavioural (i.e., oculometry) and physiological (i.e., electroencephalography and vaginal plethysmography) to conjointly predict subjective sexual feelings (i.e., subjective sexual presence), this, using a sample of 12 heterosexual cisgendered women. Measurements pertained to the participants living a sexual immersion (via a virtual reality headset) with an opposite sex virtual character engaging in sexually suggestive behaviour. Results suggest that all the tested behavioural and physiological measurements could play a role in the shaping of sexual presence. Results are discussed with therapeutic learning processes considerations in mind.

1 INTRODUCTION

Sexual difficulties (e.g., arousal, desire, or orgasmic disorders) are prevalent, affecting up to a third of people (Lewis et al., 2010) and impairing their sex lives and intimate relationships (Brotto et al., 2016; Caglar et al., 2020; Nappi et al., 2016; Mitchell et al., 2013). Virtual reality (VR) provides promising new treatment options for managing these difficulties, and could assist exposure-based therapy, mindfulness strategies, and cognitive restructuring (Dubé et al., 2022; Lafortune, Renaud & Dion, 2020; Lafortune et. al, 2023a). VR provides a safe, standardized, and ecologically valid way to elicit emotional, cognitive, and behavioural responses comparable to those elicited in real-life situations (Bell et al., 2020). This could offer patients a new way to safely experience typically feared or avoided sexual situations, and for clinicians, a new tool to recreate, closely monitor, and provide symptom-adjusted exposure to different levels of sexual explicitness, to decrease the sexual stimuli's tendency to trigger the conditioned aversive response (e.g., performance concerns, pain catastrophizing), through habituation and extinction processes. The fictional aspect, controllability, and versatility of VR, can also facilitate safer exposure in an environment free from real-world hazards (e.g., sexual assault, pressure, or rejection) compared to in vivo therapy (Lafortune et al., 2023).

VR has shown promise in treating erectile disorder, premature ejaculation, and female orgasmic disorder (Optale et al., 1997, 1998, 2003; Vila et al., 2023), and ongoing studies are currently examining clinical effects of VR exposure therapy for vaginismus and sexual aversion disorders (Brown & Brotto, 2023; Lafortune et al., 2023). Alongside, accumulating data suggest VR potential to more effectively explore and assess sexual preference-based response patterns (Fromberger et al., 2018; Marschall-Lévesque et al., 2018; Renaud et al., 2013; Trottier et al., 2015). However, there has been very little research concerning female sexual response and VR technologies, as well as the mechanisms that could

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foster or explain therapeutic changes in VR sex therapy.

2 RELATED WORKS

2.1 Sexual Presence: Enacting Affordances in Virtual Intimate Contexts

The concept of sexual telepresence or sexual presence (SP) refers to a psychophysiological technologically induced state of sexual arousal that includes a subjective erotic perception (Saint-Pierre Côté et al., 2024; Brideau-Duquette & Renaud, 2023; Milani et al., 2022). This perception is shaped by the interplay of individual psychobiological predispositions, idiosyncratic past experiences, and the sexual affordances offered by a mediating technology.

Sexual affordance in turn refers to the possibilities for action that are offered by an environment or object, which resonate with sexual behaviours and arousal (Renaud et al., 2013; Renaud et al., 2010). This concept is grounded in the Gibsonian ecological approach and the 4E cognition perspective (Gibson, 2014; Newen et al., 2018), suggesting that sexual behaviours and arousal are influenced by the affordances perceived in the environment. The interconnection between sexual presence and sexual affordance is thus understood in terms of how environments, objects, or technologies may offer cues or opportunities that resonate with and potentially elicit sexual behaviours and responses.

The concept of sexual affordance thus refers to the qualities or properties of a virtual environment that suggest possible sexual actions to a person. These affordances are perceived opportunities for sexual behaviour that the environment offers, and they are dependent on the individual's ability to recognize and enact them.

Enaction is the very process by which an individual actualizes or carries out these affordances (Bruineberg & Rietveld, 2014, 2019; Friston, 2022). When an individual recognizes a sexual affordance in a virtual environment, she may become sexually aroused or engaged, leading to a sense of sexual presence. Sexual presence, again, is the state of being psychologically and physiologically immersed in a sexual experience, which is facilitated by the enaction of sexual affordances.

Integrating this understanding of enaction with sexual affordance, we can say that the enaction of simulated affordances contributes to the sense of sexual presence by allowing individuals to engage with the virtual environment in a manner that is meaningful to their sexual behaviours and responses. This engagement through enaction is what makes the sexual affordances in virtual environments compelling and effective for the individual experiencing them.

The perceptuomotor dynamic coupling between an individual and the virtual environment's simulated sexual properties thus leads to the emergence of specific affordances. The state of sexual arousal interacts intricately with attentional processes, allowing for the extraction of critical invariances that direct sexual behaviour. It is through this enmeshing of arousal and focused attention that one engages with the virtual environment, culminating in the experience of sexual presence. This phenomenon illustrates not just the recognition of sexual affordances but their embodiment through enaction, which in turn reinforces the sense of presence. It is furthermore a crucial aspect to consider in the therapeutic learning objectives for treating female sexual dysfunctions, as it can inform how virtual environments might be designed to facilitate specific therapeutic outcomes.

2.2 Neurodynamics of Sexual Presence

At the level of neurodynamics, the understanding of the enaction of affordances that leads to sexual presence takes a significant turn by focusing on how neural circuits synchronize to extract guiding features from the environment and contexts during attraction, courtship, and sexual interaction (Saint-Pierre Côté et al., 2024; Brideau-Duquette et al., 2024; Bruineberg & Rietveld, 2014, 2019; Pfaus et al., 2023). The understanding of how neural activation underlies the recognition and enactment of sexual affordances is critical. It bridges the gap between the abstract concept of potential actions within an environment and the concrete physiological and psychological experiences of an individual engaging in those actions. This link is particularly relevant for addressing sexual dysfunctions, as it provides a framework for developing therapeutic interventions that are attuned to the individual's interaction with their environment, mediated by their neurodynamics.

In this respect, frontal EEG activity, specifically frontal alpha asymmetry (FAA), is posited as an indicator of approach or avoidance motivation and motor inhibition success (e.g., Prause et al., 2014). The simultaneous considering, in virtual immersion contexts, of EEG patterns, oculomotor signals, and measures of physiological sexual arousal highlight complex interrelations (Saint-Pierre Côté et al., 2024; Brideau-Duquette et al., 2024; Côté et al., 2021; Renaud et al., 2019). This interplay is particularly significant as it is encompassed within the broader subjective phenomenon of sexual presence, suggesting that the subjective experience of sexual presence is intricately linked with, and potentially discernible through, these psychophysiological signals.

Our primary research goal is to elucidate the intricate dynamics between female sexual arousal and the sense of sexual presence within virtual reality environments. By doing so, we aim to operationally delineate the functional relationships between therapeutic learning objectives in addressing female sexual dysfunctions and the impacts elicited by virtual reality simulations. This foundational step is critical for precisely mapping the operant conditioning contingencies inherent to synthetic environments onto the perceptuomotor and physiological facets of the organismic response we seek to alter; in turn, said facets could guide clinical interventions. Our study begins by examining the synergy between visual-behavioural indicators, cerebral neurodynamics, and sexual arousal. It then integrates these elements to assess their collective influence on the emergence of a sense of sexual presence.

3 CURRENT EXPERIMENT

The data used for this paper had been collected in a study in which participants encountered four immersive conditions wherein a Virtual Character (VC) engaged in sexually arousing movements. For the purposes of this paper, our focus is solely on the initial immersive condition, wherein female participants found themselves in a bedroom alongside a VC they had previously customized to embody an ideal sexual partner.

This study enlisted twelve heterosexual ad cisgendered women aged between 20 and 30 years, M_{age} = 23.7 years, SD = 3.92). Each participant was compensated with 70 CAD for their involvement. The research obtained ethical clearance from the Université du Québec en Outaouais, École de technologie supérieure, and Université de Montréal.

4 MATERIALS AND METHODS

4.1 Modelling and Animation Software

The Unity game engine (Version 2020.3.36, Unity Software Inc.) was employed to model and render the virtual environment (VE). The VC utilized in this environment was obtained from the Genesis 8 collection (Daz3D, Daz Production Inc.). Animation for the character was achieved through a motion capture session featuring a male performer, utilizing eight Prime13 cameras and Motive: Body software (Version 2.3.1, NaturalPoint Inc.). The animation production process was made using MotionBuilder software (Version 2019, Autodesk Inc.).

4.2 Virtual Reality Apparatus

The experiment took place within our laboratory located at École de Technologie supérieure. The computer employed wasoutfitted with an 8GB Nvidia GeForce RTX 3080 graphics cardand an Intel Core i7-10700K processor, complemented by 32 GB of RAM. The visualization device utilized was the HTC Vive Pro Eye HMD.

4.3 Measurements Instruments

4.3.1 Electroencephalography

EEG measurements were obtained using a 32-active electrode EEG cap adhering to the 10-20 system (Acticap, Brain Vision). Real-time amplification of the EEG signal was executed with the ActiChamp amplifier from Brain Vision and recorded using Brain Vision's MOVE and Recorder software (Version 1.20.0401, Brain Vision). The online reference point was established at Cz. EEG sampling rate was set at 500 Hz, and online filtering was implemented, encompassing a low-pass filter at 1.59 Hz, a high-pass filter at 70 Hz, and a notch filter at 60 Hz. Preprocessing of the EEG data was performed using Analyzer software (Version 2.1, Brain Vision). Channels deemed noisy upon visual inspection were excluded from the analysis. Spontaneous and isolated artifacts unrelated to eye movement were manually eliminated. Subsequently, all channels were re-referenced to the mean of the mastoids. Ocular Independent Component Analysis (ICA) further contributed to artifact removal, employing the meaned slope algorithm, the given condition’s dataset, and the Infomax and sum of squared correlations methods available in Analyzer. Components specifically related to horizontal or vertical ocular artifacts were removed. Frontal alpha asymmetry (FAA) scores were calculated for F4-F3 and F8-F7 pairs. Prior to computing the asymmetry, a natural logarithm transformation was applied to standardize the data distribution, as per Equation 1 (e.g., (Smith et al., 2017)

$$LN(EEGright) - LN(EEGleft) \tag{1}$$

4.3.2 Vaginal Plethysmography

The vaginal plethysmograph (VPG) is constructed from transparent acrylic plastic and is designed in the shape of a menstrual tampon. Integrated into the device is an infrared light- emitting diode (LED) that projects light toward the vaginal wall. A portion of this light is reflected to a phototransistor situated within the probe, while the remaining light is expected to disperse through the vaginal tissue; researchers typically hypothesize that an elevated amount of returned light to the phototransistor corresponds to an increase in blood volume in the vaginal blood vessels (see Prause & Janssen, 2005). This alteration is quantified as a change in millivolts (mV) from a baseline value. In this manuscript, we examine the alternating current, signal, also known as vaginal pulse amplitude. This signal is believed to reflect variations in pressure within the blood vessels of the vascular walls of the vagina. We filtered the signal with a low- pass filter to remove high frequency noise. We then computed the mean (M), standard deviation (SD) and variation coefficient (VC) of the signal. We also computed the area under the curve (AUC) of the signal.

4.3.3 Oculometry

Eye movement data were captured using the HTC Corporation's SRanipal software development kit via the headset, with a sampling rate of 90 Hz. The eye-tracking precision of the HTC Vive Pro Eye system ranges between 0.5 and 1.1 degrees. The Gaze Radial Angular Deviation (GRAD) is determined by assessing the angle between two vectors: one connecting the eye's center to a virtual measurement point (VMP), and the other representing the normalized eye direction acquired directly through SRanipal. In our context, the VMP was located on the VC. Evaluation of the direction and consistency of visual search behaviour involves computing the mean (GRAD Mean) and its standard deviation (GRAD SD), respectively. The GRAD variation coefficient (GARD CV) in turn is a standardized measure of dispersion of a probability distribution or frequency distribution (SD/AVG). The GRAD's related variables were computed offline using a custom program developed in MATLAB (version R2021B, The MathWorks Inc., Natick, USA).

4.3.4 Questionnaires

To gain insights into participants' subjective sexual experiences during virtual exposure, the Sexual Presence Questionnaire was used (Renaud et al., 2019), with items adapted for the immersive context when applicable. It consisted of three questions gauging realism and seven questions assessing involvement. The overall subjective presence score was then determined by summing the scores of these two subscales.

4.4 Data Analysis

We analysed data focusing on a particular segment of the animation, specifically when the VC engages in sexually explicit movements. This sequence unfolds 25 seconds after the VC first appears in the Virtual Environment (VE) and spans a duration of 30 seconds. We conducted two regression analysis to predict VPG AUC and Self-Reported Sexual Presence (SP). This involved leveraging the collected data from quantitative electroencephalography (qEEG), vaginal plethysmography (VPG) and oculometry.

5 RESULTS

To explore potential relationships between the triangulated variables, bivariate correlations were computed and are presented in Table 1.

Noteworthy correlations emerged, including a significant association between Self-reported Sexual Presence and the AUC of the VPG signal ($r = 0.66$, $p = 0.021$). Additionally, significant correlations were identified between AUC of the VPG signal and two other variables of interest: the relative asymmetry in F8 and F7 in the Alpha band ($r = -0.68$, $p = 0.03$) and the variation coefficient of the Gaze Radial Angular Deviation (GRAD CV) ($r = -0.62$, $p = 0.03$).

In the linear model proposed to predict the AUC of the VPG signal (Table 2), the relative asymmetry in F8 and F7 in the Alpha band ($\beta = -0.55$, $p = 0.019$) and the variation coefficient of the Gaze Radial Angular Deviation ($\beta = -0.54$, $p = 0.02$) collectively contribute to explaining 60% of the observed variance. The residuals of the regression display linearity are conformed to a normal distribution (Shapiro-Wilk: $p = 0.15$) and demonstrate homoscedasticity.

Table 1: Bivariate correlations between AUC of the VPG signal, qEEG relative asymmetry in frontal regions and GRAD variables.

	SP	VPG (AUC)	EEG (F4-F3)	EEG (F8-F7)	GRAD (M)	GRAD (SD)	GRAD (CV)
PS	1						
VPG (AUC)	0.66 *	1					
EEG (F4-F3)	-0.16	0.28	1				
EEG (F8-F7)	-0.44	-0.68 *	-0.17	1			
GRAD (M)	-0.18	0.41	0.09	-0.10	1		
GRAD (SD)	-0.49	-0.12	0.10	0.18	0. 51	1	
GRAD (CV)	-0.13	-0.62 *	-0.10	0.15	-0.83 **	0.03	1

Note: *p < 0.05, **p <0. 01, ***p < 0.001.

Table 2: Linear model of predictors of the AUC the VPG measure (n = 12). 95% confidence intervals reported in brackets.

	b	*SE B*	*β*	*p*
Constant	365.57 [348.46, 383.01]	3.29		< 0.001
qEEG (F8-F7)	-27.96 [-50.17, -5.71]	9.82	-0.55	0.019
GRAD (CV)	-45.38 [-82.05, -8.70]	16.21	-0.54	0.021

Note: R = 0.82, R2 = 0.68, Adjusted R2 = 0.60, F = 9.36, p = 0.006

In the linear model for predicting Self-Reported Sexual Presence (Table 3), the AUC of the VPG signal ($\beta = 0.98$, $p < 0.001$), the mean Gaze Radial Angular Deviation ($\beta = -0.55$, $p = 0.013$), and the relative asymmetry in F4 and F3 in the Alpha band ($\beta = -0.38$, $p = 0.049$) collectively contribute to explaining 73% of the observed variance in sexual presence. The residuals of the regression demonstrate linearity, conformity to a normal distribution (Shapiro-Wilk: p= 0.20), and exhibit homoscedasticity.

Table 3: Linear model of predictors of Sexual presence (n = 12). 95% confidence intervals reported in brackets.

	b	*SE B*	*β*	*p*
Constant	-746.22 [-1086.34, -406.10]	147.49		< 0.001
VPG (AUC)	2.36 [1.37, 3.36]	0.43	0.98	< 0.001
GRAD (M)	-2.82 [-4.87, -0.77]	0.89	- 0.55	0.013
qEEG (F4-F3)	-28.38 [-56.65, -0.11]	12.26	- 0.38	0.049

Note: R = 0.90, R2 = 0.80, Adjusted R2 = 0.73, F = 10.78, p = 0.003

6 DISCUSSION

This study examined the relationships between genital, ocular, electroencephalographic and sexual presence scores, all in the context of a VR immersion with a personalized VC.

The first regression model revealed robust correlations between gaze behaviour and FAA with the AUC of the VPG signal. This indicates that a substantial understanding of female physiological sexual arousal can be achieved by accessing data on brain and gaze dynamics during interactions with sexual virtual content. More specifically, female sexual preparedness is associated with less gaze dispersion around the visual object of interest and more pronounced asymmetrical frontal brain activation.

The second regression model showed even stronger correlations between psychophysiological predictors (i.e., VPG, GRAD and FAA) and self-reported sexual presence, providing insights into how these variables can predict SP level or the impression of realism and sexual engagement felt during our VR simulation.

Examining the coefficients of these factors, we observe that each of them significantly and independently contributes to sexual presence scores. Peripheral genital arousal appears to be strongly linked with increased sexual presence levels. Increased radial angular deviation of gaze is negatively correlated with sexual presence, impression of realism and sexual engagement, suggesting that a more focalized attention on critical cues of the sexual stimulus plays a role in inducing sexual presence. Finally, frontal alpha asymmetry, which is posited as an indicator of approach or avoidance motivation, has a negative coefficient. That decreased of frontal alpha EEG activity on the right side relative to the left is associated with heightened levels of sexual presence seems to go counter to the "approach/avoid" interpretation of FAA (i.e., more sexual presence is associated with "avoidance" FAA). However, the present results fit with earlier accounts of FAA in sexual contexts (Prause et al., 2014; Renaud et al., 2019).

Overall, it appears that sexual presence is strongly associated with a psychophysiological pattern, which is concordant with the latter partly shaping sexual presence. What is achieved here with simple statistical regressions could very well be tapped into with more predictive and control power by using machine learning methods (Côté et al., 2021; Galaup et al., 2024).

Limitations of this study include the small sample size of participants, which diminishes the statistical strength of the presented analyses, the correlational statistical approach which prevents causal inferences about SP, and the relative lack of diversity (i.e., heterosexual and cisgender) within the sample.

7 CONCLUSION

A key insight to retain here in terms of learning pertains to the importance of focused attention in the enacting of affordances. The observed negative correlation between gaze dispersion and sexual presence underscores the potential of attention training in sex therapy protocols. Techniques that enhance the ability to focus on sexual stimuli could aid in improving sexual response and functioning. Training modalities could include mindfulness-based practices or attention control exercises designed to reduce cognitive distractions and increase mental presence during sexual activity.

The significance of visual-behavioural indicators also points towards the utility of cognitive-behavioural techniques. Such interventions can help in restructuring cognitive patterns, managing maladaptive attentional strategies or biases, and reduce (experiential) avoidance behaviours that may hinder sexual arousal. By focusing on the cognitive and behavioural components of sexual response, therapists can work with patients to develop healthier sexual attention and engagement patterns.

Neurofeedback emerges as another promising avenue for treatment, given the relationship between frontal alpha asymmetry and sexual presence. This method could enable individuals to gain control over their brain activity, potentially leading to improved sexual arousal patterns. By providing real-time feedback on brain wave patterns, VR-mediated neurofeedback could help patients learn to modulate their physiological responses in ways that may enhance sexual engagement and satisfaction.

The integrative nature of sexual arousal, as revealed by the study, implies that a combination of physiological and psychological strategies may yield the best treatment outcomes. Incorporating VR technology into therapy could simulate intimate situations, allowing patients to navigate and manage their responses to sexual stimuli within a controlled, therapeutic setting. This could be particularly useful for exposure therapy and the practice of skills learned through other treatment modalities.

Lastly, the potential for data-driven treatment approaches based on machine learning applications, could be a game changer to the field (Côté et al., 2021; Galaup et al., 2024). These methods offer the prospect of developing predictive models that tailor interventions to the unique psychophysiological profile of everyone, optimizing treatment outcomes and leading to more nuanced and effective therapies.

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