Research Article

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Shared multisensory sexual arousal in virtual reality (VR) environments

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Abstract: This research explores multisensory sexual arousal in men and women, and how it can be implemented and shared between multiple individuals in Virtual Reality (VR). This is achieved through the stimulation of human senses with immersive technology including visual, olfactory, auditory, and haptic triggers. Participants are invited to VR to test various sensory triggers and assess them as sexually arousing or not. A literature review on VR experiments related to sexuality, the concepts of perception and multisensory experiments, and data collected from self-reports was used to conclude. The goal of this research is to establish that sexual arousal is a multisensory event that may or may not be linked to the presence or thought of the intended object of desire (sexual partner). By examining what stimulates arousal, we better understand the multisensory capacity of humans, leading not only to richer sexual experiences but also to the further development of wearable sextech products, soft robotics, and multisensory learning machines. This understanding helps with other research related to human-robot interaction, affection, detection, and transmission in both physical and virtual realities, and how VR technology can help to design a new generation of sex robots.

Keywords: multisensory sexual arousal, virtual reality, cybersex, sextech, immersive environments

1 Introduction

Technology is exponentially pushing humans into new realms of existence. We create better and smarter ways of living, and sex is no exception. Technological innovations

in sex are defining our future generations and changing how we express intimacy and love and how we see and relate to ourselves and others. Over the course of the past century, the rise of feminism and developments in information technology [1] is challenging the traditional association of sex with childbirth and its contributions toward separation, freeing sexual desire from reproduction. Electric technology allows humans to extend their nervous system or set it outside themselves [2]. Sex is a fundamental part of our existence and is no less suitable for technological extensions like any other aspect of living. This could well lead us into a new era of sexual experience which is no longer restricted by the limitations of the human body. Human beings are transforming and so is sex.

1.1 Perceptual and sensory processing

Abilities to see, hear, smell, touch, and taste paint the world that we experience. “The immediate objects of the perception of our senses are merely particular states induced in the nerves” [3]. It can be said that “the world” does not exist; rather, “the world” is a reflection of the sophisticated patterns of neural activity which is never the same. “Perception involves ‘symbolic’ representations, in which the state of the world is described using a limited set of abstract symbols” [4]. It can be suggested that if we were to take any moment in time and take away some of its preceptive properties, it will no longer symbolize the given moment, leading to the thought that natural objects and events in life are usually multisensory. “Senses are capable of only limited perceptions when operating in isolation” [5].

We also know from sensory neuroscience that “a growing body of research demonstrates that information is shared across sensory modalities and there is strong evidence that information provided by one sense can influence the perceptual quality of stimuli impinging on a different sense” [4]. This means that information about the world from one sense is simultaneously influencing and is influenced by the information coming from other senses to build up a full perception of the world from the

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information coming from all senses. This effect is called cross-modalism. Several studies have been done to find evidence for cross-modal links between senses and are referenced in Nager, Estorf, Münte (2006) research article concluding that “Attention to points in space in one modality boosts the neural responses to task-irrelevant stimuli from the same location in another modality” [6].

According to Jutte [5], the history of senses is “fragmented” and derives from the uncomplete social understandings of human perception and individual historical episodes, meaning that senses have been readjusting their significance and values to cultural needs in time. Thus, some senses developed to be predominant over the others. Jutte [5] argues that the nineteenth century led to big changes in perception which primarily affected extension of the sense of sight. According to him, these changes were influenced by the switch from steam to electricity; the development of the wireless telegraph and telephone; the invention of camera obscura, stereoscope, microscope, and telescope; and more. On the contrary, hearing and smell became dulled as it suffered the negative side effects associated with ever-increasing noise and smell pollution.

The sense of touch only started developing its significance in the twentieth century with the increased interest in sensory physiology and inventions of touch screens, keyboard, mouse, and interactive monitors.

Sigmund Freud played a key role in the re-discovery of the sense of touch and its link to sexuality by introducing a concept of “erogenous zones” [7].

In the famous Three Essays on Sexual Theory of 1904–1905, Freud claims that “satisfaction arises first and foremost from the appropriate stimulation of what we have described as erotogenic zones” [7]. However, the discovery of the significance of the sense of touch in human sexuality wasn’t only Freud’s work. He was heavily influenced by the writing of Henry Havelock Ellis who earlier described the sense of touch and the sexual skin centers in particular [5].

However, human erogenocity is far broader than Freudians depict. Iwan Bloch had a strong view that under certain cultural conditions (context), any sense organ can function as an erogenous zone [5]. We believe this is precise, as the pallet of sexual arousal/excitation is far broader and far more complex than the constrained “erogenous zones.” It is a combination of a desire with what one sees, hears, smells, and feels that makes them sexually aroused. A simple case in point is the observational wrist example: a touch on a wrist can cause unpleasant or no effect on a receiver if the context and environmental settings are unappealing; if we change one or more preceptive properties, the same touch on a wrist can cause pleasurable and arousing sensations.

1.2 Virtual reality (VR)

The idea of sensory extension is not new. It was introduced to the masses during the twentieth century with the rise of sci-fi books [8,9] and films [10–14], which promoted high-tech ideas of cyberspace and virtuality. However, the first iterations of cyberspace originated earlier. It started with the development of the first telegraph and the first love messages encoded into the Morse code, which ultimately evolved into the emergence of the Internet. The active use of sex-based chats quickly became very popular and created a whole new means for safe and anonymous self-expression giving birth to a new term – “cybersex.” Faster Internet connections rapidly expanded cybersex from chats to porn videos, synchronized live-cams, real-time 3D games, and VR [15,16].

The majority of current VR sex-related experiences [17–21,22–26] are usually one-way experiences that solely rely on the literal visual representation of sex and genital stimulation. These offerings are either 360 degree filmed [18–21] and/or computer-generated [20,23,25,26] pornographic videos or more interactive VR experiences [17,22,24] that allow users to create their own highly customizable 3D avatars, decorate houses, meet people, visit different scenarios, participate in games, and chat in a safe environment. However, these and many other sextech products lack sensory relevance, focusing solely on the path to orgasm, taking the richness of the sensory palette out of the equation.

Men and women have different arousal responses to visual sexual content. For example, the amygdala and hypothalamus are more strongly activated in men than in women when viewing identical sexual stimuli [27]. Even though men are generally considered more aroused than women because of visual stimuli, for example, during a VR session, different factors, including participant variables such as hormonal state, socialized sexual attitudes, and variables specific to the content being presented [28] may also contribute to the effect of a VR experiment on creating sexual arousal. VR technology is already being used in research related to sexuality. A study measured the dynamics of the subjective point of view (POV) during a VR session for assessing sexual preferences when the subject interacted with a virtual naked model [29]. Also, VR was used in the forensic assessment of deviant sexual preferences. In this work, an experiment was conducted to measure the sexual arousal among sex offenders of children, and the VR modality was compared to a conventional method. VR allowed a significantly higher classification accuracy [30]. Researchers also demonstrated that VR has the ability to induce a feeling of presence to the user, by stimulating different emotions and contributing to affective interactions within the virtual world [31].

The aim of this article is to propose evidence for sexual arousal to be seen as a multisensory event through the use of VR and examine how it can be shared between individuals in VR. As a result, this article will convey more visibility into what combinations of sensory triggers are perceived as arousing in cyberspace and affirm the urge for further in-depth human-centered research set to take place in the next phase of studies.

2 Methods

2.1 Participants

It is considered that the intentionality of a desire is what differentiates human sexuality from animalistic mating [32]. To validate whether the intention and object of a desire are necessary for the virtual settings, we introduced two groups for research – “Solo” and “Couple.” The difference between both was the presence of a sexual partner in the latter. The “Couple” group was then split into the “Receiver” (equipped with the wearable device incorporating haptic feedback and scents) and the “Giver” (no wearable device) to investigate what impact tactile sensations and scents have on the arousal level in VR. During the experiment, “Receiver” and “Giver” were located in different study rooms.

In all 140 adults (69 female, 64 male, 6 non-binary, and 1 transgender) aged 18 to 64 (mean age 29) participated in the study. Fifty-two individuals (27 female, 24 male, and 1 non-binary) participated in the “Solo” experience, while 88 (42 female, 40 male, 5 non-binary, and 1 transgender) participated in the “Couple.” All subjects were in good health and free from psychoactive substances. After receiving an explanation of the experiment, subjects gave written and verbal informed consent to participate. All participants were free to withdraw from the research at any time.

2.2 Stimuli

Whether a particular stimulus is experienced as sexually appealing depends on the context in which one perceives it. The dual-control model of sexual response describes the central mechanism that controls how and when humans respond to sexually relevant sights, sounds, sensations, and ideas. The dual-control model proposes two control mechanisms – Sexual Excitation System (SES) – accelerator – receives information about sexually relevant stimuli in the environment; and Sexual Inhibition System (SIS) – brakes – the opposite, looking for cues to say no [33,34]. Both SES and SIS are unchangeable traits that remain

stable over the life span. It would be impossible to create one set of sensory combinations that would affect everyone’s SES as their characteristics and sensitivities vary from person to person, leading to different arousability. However, every SES and SIS respond to the common pattern, known as “stress response cycle,” which is present in every human behavior. The complete stress cycle begins from “I’m at risk” and ends at “I am safe.” SIS is more likely to activate during times of stress and danger, whereas SES goes into effect during times of peace and emotional stability, thus increasing the chances of arousability at the latter [33,34].

With that in mind, our goal was to manually place participants at the end of the stress cycle before and during VR sessions by creating controlled multisensory environment (MSE), also known as Snoezelen, which is often used for therapeutical purposes for people with autism, dementia, or brain injuries [35].

To conduct the experiment, we used existing Oculus Quest VR HMD (Figure 1) and designed a bespoke wearable haptic-olfactory device, immersive virtual, and physical MSEs.

2.2.1 Oculus Quest

We used two of Oculus Quest VR HMD to run the experiment. The device is fully standalone, features two, six degrees of freedom controllers, and runs on a Qualcomm Snapdragon 835 system on chip. The Oculus Quest uses two diamond Pentile OLED displays; each with an individual resolution of $1,440 \times 1,600$ and a refresh rate of 72 Hz.

2.2.2 Wearable

The wearable device was designed to transmit scents and “tactile sensations” from a virtual avatar over Bluetooth (Figure 2). The device was paired with the server and received signals of touch events from VR in real time. The “touch” was simulated with three pairs of vibrating motors – a pair on each arm and the chest. Scents were emitted

Figure 1: Oculus Quest untethered VR HMD and 2 touch controllers.

Figure 2: Photograph of a wearable device designed for the experiment.

through the 3D printed collar which was placed over the participant's shoulders. Two fans at the back of the collar pushed the scent through the structure, releasing it throughout the opening in front. The device emitted two types of scents, Odor #1 and Odor #2. Odor #1 was constructed as a warm, sensual rose composition with fresh naturalistic top notes. The smell was designed to be pleasant and inviting with biological associations, e.g., pulsation, warmth, and moisture. For the second odor, the composition centered on the idea of "human leather," incorporating various musky elements to evoke the scent of human skin in sunlight [36]. Both were linked to the real-time events in VR. The system communication diagram is represented in Figure 3. The computer was responsible for running the VR application, which was developed in C# using the Unity development platform but also for communicating with the other parts of the system. Each subject wore a VR headset, but only

a "Receiver" wore a backpack containing the hardware responsible for activating the vibration motors and fans of the scent emitter. The main component of the hardware was the ESP32 board, which was capable of communicating wirelessly with a computer; it had output pins that could activate the drivers for controlling motors and fans. The information sent from the computer to the ESP32 board was synced with the VR content and used for activating the motors and scents for both subjects.

2.2.3 Immersive virtual multisensory environment (VMSEs)

We designed three types of VMSEs to stimulate arousal in VR. We built them intending to raise sexual accelerators (SES) from neutral to eager (0–1). The "neutral" stands for "relevant," meaning that the cue is neither arousing nor allaying. When cue becomes not only relevant but also exciting, it gives rise to "enjoyment," which then progresses into "eagerness" when the subject asks for more. To trigger "eagerness" we introduced various sensory cues relating to different arousal types to investigate what demo- and psychographics resonate with them [33,34]. We approached content creation intending to challenge socially induced stereotypes and literal representations introducing concepts of "abstract sexuality" and virtual intimacy.

2.2.3.1 Intro

The first VMSE was designed to be a safe space to activate SES. We used binaural autonomous sensory meridian response (ASMR) [37] narration and virtual clouds ranging between deep purple and pink to create a "safe space" and prepare participants for the erotic journey into the unknown (Figure 4). The buildup began with the release of scent #1, ASMR progression into the music and the movement of the virtual point of view into a large tunnel resembling the vulva

Figure 3: Block diagram with hardware components of the system and communication protocols.

Figure 4: Screenshot of Intro VMSE first part taken from Oculus Quest.

Figure 5: Screenshot of Intro VMSE progression into vulva-like tunnel taken from Oculus Quest.

(Figure 5). Its contractions were synchronized to the beat. No interaction with the VMSE was expected at this point. The total duration for “Intro” was 02:10 min.

2.2.3.2 Void

We designed the second VMSE to be the most intimate and abstract using ASMR, music, procedural event-based virtual graphics, and tactile feedback. This was the first VMSE where participants saw their virtual bodies and were able to interact with them. Their bodies appeared as humanoid figures but were not designed to look like “realistic” humans. Their bodies were built out of thread-like spines resembling the nervous system (Figure 6).

“Touch events” in VR were transmitted as 2-second vibrations through the device that participants in the “Solo” group and “Receiver” scenario wore. Additionally, we programmed direct visual and auditory responses to the touch in the form of localized particles originating from the places of touch and the sound effect of a piano key. We used repetitive ASMR audio cues to encourage participants to touch.

All visual cues were linked to the “touch” events, meaning that every engagement with the sense of touch

Figure 6: Two cis gender virtual avatars.

Figure 7: Screenshot of void VMSE taken from Oculus Quest. Subject 1 is touching Subject 2.

(in the “Solo” group participants had to touch their virtual body and in the “Couple” their partners) unlocked new iterations of visual cues (Figure 7). We programmed 35 iterations for the “Solo” group and 65 for the “Couple” group. This event-based procedure progressed from complete darkness to emerging particles of lights building up into the universe triggering trails of particles to swirl around the participants and eventually opening a light tunnel which was a transition to the next and final VMSE.

2.2.3.3 Orgy

The third and the last VMSE we designed to be the most explicit and representational. Participants were placed in the middle of 3D computer-generated (CG) orgy deploying various sexual acts. We designed CG models to look like biological humans, but kept their skins untextured and avoided any signs of personalized traits to minimize chances of evoked memories and associations and to ease in the perceptual transition to “abstract sex” (Figure 8).

We used ASMR recordings and scent #2 to maximize immersion. The total duration for this VMSE was 02:30 min.

Figure 8: Screenshot of orgy VMSE taken from Oculus Quest. The 3D CG models engaging in various sexual acts.

2.2.4 Physical MSE

We created intimate and relaxing settings in the waiting room using dimmed colored LEDs [38,39], ambient nature sounds [40], and burning incense. It was the investigator's responsibility to set up the relevant mood and reduce participants' stress levels by building trust and personal connections through conversation before proceeding with the trial. We maintained 20°C temperature [41,42] in the study rooms and used two-colored LED lamps, namely, blue and pink [38,39], to maintain the mood.

2.3 Procedure

Participants arrived at the reception and were escorted to the waiting room by the research assistant. There they were greeted by the investigator playing the role of a hostess. Participants were asked to get comfortable and take a seat on the sofa. They were then briefed on the experiment and were given informed consent forms to sign. The "Couple" group participants were asked to make their "Receiver" and "Giver" choices at this time. Participants were then taken in the separate study rooms where they were given safety instructions and equipped with the wearable device, VR headset, and headphones. Once in VR, participants had to select "which gender they would like to be" to start VMSE 1 – "Intro." All VMSEs were linked and played automatically one after another. In the "Couple" group, "Intro" was experienced by each participant privately, whereas "Void" and "Orgy" were shared with the partner. Both participants were located in different rooms but reunited in the virtual space when entered "Void."

When the last VMSE ended, we helped participants to take off the equipment and brought them back to the waiting room to fill in the self-report forms. We allowed 25 min per session including greeting, briefing, experience and self-reporting.

2.4 Recording and analysis

Our qualitative data collection approach involved self-report forms filled in by participants immediately after the trial, investigator's observations and direct interactions with participants on a one-to-one basis and in a group setting.

Self-report forms were split into three parts: Research, Product Development, and Demographics. Questions ranged between multiple choice, checkboxes, linear scale from 0 (lowest) to 5 (highest), and free form answers. Participants were asked to assess their arousal

levels before, during, and after the trial. Each subject's data were normalized and clustered to allow group comparisons. Contrasts were applied to the parameter estimates for each VMSE to identify areas and levels of arousal versus an implicit rest period. Information about arousal levels was extracted and projected onto graphs depicted below.

3 Results

Participants from "Couple" and "Solo" groups reported almost identical levels of sexual arousal. The difference between both was found to be insignificant. Participants were asked to rate the level of their sexual arousal at the moment when they just came out of the experience on a scale of 0–5. In the "Couple" group, 39.8% of participants rated their arousal level between 0 and 1, 48.8% between 2 and 3, and 11.3% between 4 and 5. In the "Solo" scenario, 46.1% of participants rated their arousal level between 0 and 1, 51.9% between 2 and 3, and 9.6% between 4 and 5. Both can be seen in Figure 9.

These figures show increased arousal levels compared to pre-trial states reported in the forms. These confirm that in the "Couple" group, 61.4% of participants reported their arousal level between 0 and 1, 35.2% between 2 and 3, and 3.4% between 4 and 5. In the "Solo" scenario, 84.6% of participants rated their pre-trial arousal between 0 and 1, 11.9% between 2 and 3, and 1.9% between 4 and 5. Both are seen in Figure 10.

How sexually aroused did you feel when you just came out of the experience?

52 responses

"Solo" Subjects

88 responses

"Couple" Subjects

Figure 9: Charts indicating arousal level after the experience in "Solo" (above) and "Couple" (below) subjects extracted from the self-report forms.

Figure 10: Charts indicating arousal level before the experience in "Solo" (above) and "Couple" (below) subjects extracted from the self-report forms.

Within the "Couple" group, "Receivers" reported the highest arousal levels; 25.5% participants rated their arousal level between 0 and 1, 60% between 2 and 3, and 14.5% between 4 and 5.

Whereas "Givers" reported 51.1% between 0 and 1, 41% between 2 and 3, and 7.9% between 4 and 5 (Figure 11).

If we project these findings on a scale from 0 to 1 (from neutral to eager), we can see that over half the total amount of participants had a rise in sexual accelerators, thus showing an increased arousal level by the end of their session (Figure 12).

Figure 11: Charts indicating arousal level after the experience in "Receiver" (above) and "Giver" (below) subjects extracted from the self-report forms.

Figure 12: Graph showing the difference in the arousal level of all subjects before and after the experience.

Within the VMSEs, 61.5% of "Solo" participants rated "Orgy" as the most arousing part of experience, 11% – "Intro," 3.8% – "Void," and 23% reported "other" cues. Participants identified visual stimuli as the most arousing, followed by sound, scents, and tactile sensations. In the "Couple" group, "Receivers" rated "Void" as the most arousing – 44.2%, 25.6% – "Intro," 18.4% – "Orgy," and 12.3% reported "other" cues. Participants identified visuals, sounds and presence of a partner almost equally arousing (Figure 13).

When asked whether there was anything that pulled them off, 12.8% of all participants reported technical issues, 7% felt uncomfortable being observed and 3.6% feared of stepping out of the boundaries of the virtual world.

Figure 13: Charts showing rating of arousing elements, subjects extracted from the self-report forms. "Solo" (above) and "Coupler" (below).

4 Discussion

This study illustrates that the arousability of VMSE is not dependent on the presence of another human being, can increase sexual accelerators, and be arousing when experienced by an individual alone and in the presence of a desired partner, as the difference in arousal level between “Solo” and “Couple” group was not very significant. Our study also shows that the presence of the desired partner in VMSE can increase arousability level, as 54.5% of participants reported that the presence of their partner evoked higher arousal levels, as seen in Figure 14, and in the participant reports which determined “Void” to be the most arousing VMSE among the “Couple” group. It can be suggested that other sensory stimuli, such as visual and auditory cues, compensated on the partner’s presence for participants in the “Solo” group while remaining at high arousability level. Findings also suggest that haptic and olfactory cues increase arousal levels, attempting to prove that sexual arousal is a multisensory event and must, therefore, be treated as such. In our experiment, only the “Receiver” group was wearing a device that transmits the haptic and olfactory cues, giving us insights into the sub-groups’ arousal level, opposing “Givers” who did not wear a device and were not exposed to haptic and olfactory cues. Therefore, we suggest that haptic and olfactory cues contributed toward the higher arousal level. This suggestion is based on the comparison of “Receiver” and “Giver” reports. We did not measure the arousal level without haptic and olfactory cues within the “Receiver” sub-group. It is suggested that the results might have been different, given the measurements of the

arousal level in the experience within the same sub-group before and after the introduction of haptic and olfactory cues. However, if haptic and olfactory cues were introduced once the experience was started it would have caused disruptions and d’immersion from the experience, thus lowering the arousal levels. It is suggested that similar outcomes might have happened if participants from the same sub-groups were immersed in the same experience twice, with or without devices. Familiarity with the setting and the narrative would have lowered the arousal levels, as anticipation and novelty usually accelerates SES [33,34].

No tests have been done to investigate the effects of wearing a device by itself, however, some participants provided verbal commentary on its effects. The majority of participants who enjoyed the experience reported excitement when they were asked to wear a device – some compared it to “going on a journey” and to the “space.” These participants also reported being pleased by the visual aesthetics of the device, as it recalls sci-fi and cyberpunk associations. These participants were mainly female, 25–34, 160–170 cm height, slim. On the contrary, taller and wider participants had visible struggles wearing a backpack, and some men reported aesthetic un-appeal toward the device due to the backpack size. These participants reported lower arousal levels. It can be concluded that the initial reaction to the device somewhat predetermined either more positive or negative emotions toward the experience and affected the outcomes. It is suggested to adjust the design of the device to accommodate various body types and sizes and conduct tests on the wearing of the devices by itself before any other investigations.

Growing body of ASMR research demonstrates that not everyone is affected by ASMR. Recent studies [43] confirm that watching ASMR videos increased pleasant effect only in people who experienced ASMR. However, the aim of our experiment was not to test the effect of every stimulus separated from the others but to test the holistic effect of the experience as a whole (room, sound, haptics, visuals, and smells).

Ninety-five percent of participants identified themselves as cisgender – among them 7% chose to be a different gender in VR. The remaining 5% identified as non-binary and transgender and reported feeling uncomfortable during the gender selection process. Thus, alternative solutions should be considered in future investigations.

Eighty-nine percent of cis “Couples” assigned male to be a “Giver” and female – “Receiver.” Almost all participants performing the role of a “Giver” reported being unsatisfied with not having a wearable device. Fifty-seven percent of participants expressed a desire for enhanced tactile feedback.

Figure 14: Body maps showing the distribution of virtual touch in VR in both groups.

However, in light of the experiment, one of the participants needed to remain without a device to highlight its necessity.

Of the participants, 17.8% reported visual cues being too “abstract” and expressed a desire for more “realistic” human figures, textures, and more. It can, therefore, be surmised that a larger majority of participants are ready for new exploration in sexuality, experiencing new shapes and forms of manifestation that may come along the way. We designed this experiment to begin the discourse on what “abstract sex” can be like and to gain insight into where the current demo- and psycho-graphics sit within it. Participants with creative jobs were more likely to find abstraction arousing.

Fifty-four percent expressed a desire for longer sessions, while 17% thought that the time spent was just about right.

Observational notes also concluded the following: in the “Solo” scenario female participants on average were more likely to touch themselves as opposed to males. About half of the participants had not tried VR before this experiment. In many cases, anticipation and intrigue contributed toward arousal buildup.

Participants were located in separate study rooms; thus, their interactions were quite limited and could be performed and transmitted only in the VMSE. This methodology opens new possibilities for the development of technologies for long-distance relationships. It is suggested to introduce additional means for communication such as real-time voice transmission for future investigations.

A small number of the participants reported confusion and issues recognizing their partner in VR, while others reported distinct similarities in partners gestures, moves, height, and behavior. It was later determined through one-on-one conversations that the couples that reported recognition issues have not yet developed strong emotional bonds with their partners, opposing couples that reported distinct similarities.

We also managed to record the number and position of touch events in VR and project their intensity over a flat image (Figure 14). This was possible by creating virtual colliders and placing them inside each avatar’s body, so every time something hit them the data were captured and saved on the server. We were only able to capture this data from 75 participants (44 “Couple” and 31 “Solo”). We combined the total number of each “touch” from each participant for each collider and spread them out on a scale of 10 shades of red and orange color to paint the “touch” figures ranging between 0 and 956. Subjects in both groups interacted the most with their torso and arms. These are the places where we had vibration motors located. We can also suggest that interactions with legs were low because participants were standing during the experience, thus

interacting with legs was not as comfortable. However, participants in the “Solo” group interacted more with their legs and left hands. This can be indicative of the majority of subjects being right-handed. Participants in the “Couple” group, almost equally spread interactions among both arms and interacted more with the head than participants in the “Solo” group.

It would have been insightful to investigate this further by using a full-body suit to investigate the distribution of virtual touch when the full body has feedback rather than just the torso. In this case, we would be able to create new erogenous maps of virtual touch.

VR is already being used for studying how humans can interact with robots (Human-Robot Interaction, or HRI) [44,45]. By using VR, researchers can predict how humans would react to robots by using a virtual version of them before manufacturing physical and expensive versions. The same approach can be extended for testing human interaction with biologically inspired intelligent robots [46] and/or humanoid robots [47]. The presence of a virtual robot in the virtual environment with users’ interaction can create important insights on how humans would interact with a robot in different contexts (VR contents), on how humans would react (if body signals are measured), and how personal parameters would be important in the design to account for HRI or in a virtual context. We can also expand this concept for sexual robots (sexbots). This controversial technology is already being developed, but its pros and cons are still being discussed [48]. VR experiments could be conducted to assess which factors would be important in the context of interaction with a virtual sex robot, so by using the methodology presented in this work, researchers would be able to choose the right scenes, sounds, haptic interactions, and other stimuli, which, combined with the virtual sex robot and the personal background of the subject being tested, would create the desired arousal effect. The results of this possible experiment could be used for the design of sex robot traits and physical characteristics before manufacturing real robots.

5 Conclusion

As reality is multisensory, the virtual worlds must be convincing and disperse the disbelief. The sexual arousal measured in this study was confirmed to be a multisensory event like any other event in physical or virtual realities. It proved to follow SES and SIS mechanisms, regardless of the reality type. Multisensory sexual arousal can, therefore, be shared between multiple individuals in VR through the networked experience enhanced with wearable haptic

and olfactory devices for all participants. The audience showed initial interest in “abstract sexuality” concepts and thus needs further research to challenge assumptions about what the body is and what it can do.

The results of this work will be used in the design of new VR experiences and sexual devices, evaluating some of the parameters that are important for creating sexual arousal. The methodology presented here can also be used in the design of sexbots by helping to choose the right parameters for a VR test of the virtual version of a sexbot, thus saving time and money for robot manufacturers.

Based on this study, future work will be focused on creating a multisensory mixed reality playroom for larger groups of people to further explore the concept of “abstract sexuality,” the design and development of smart wearables and soft robotic, implementation of biosensors and into experiments and the ultimate development of a multisensory learning machine.

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Author contributions: Angelina Aleksandrovich was involved in conceptualization, investigation, administration, supervision, analysis, methodology, experiment design, direction, production, and writing original and final manuscript draft. Leonardo Mariano Gomes contributed to the development and programming of a haptic wearable and its communication with the game engine, manuscript technical writing contribution, and technical supervision. Harry Sherwood contributed to scent and olfactory hardware design and manuscript editing. Laurentiu Fenes was involved in VMSEs game engine development and technical support. Sophie Langhor was involved in 3D CG assets design. Luke Burnsright was in charge of soundtracks and SFX design. Angelika Vladimirova assisted in conducting experiments.

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