Breathing based immersive interactions for enhanced agency and body awareness: a claustrophobia motivated study

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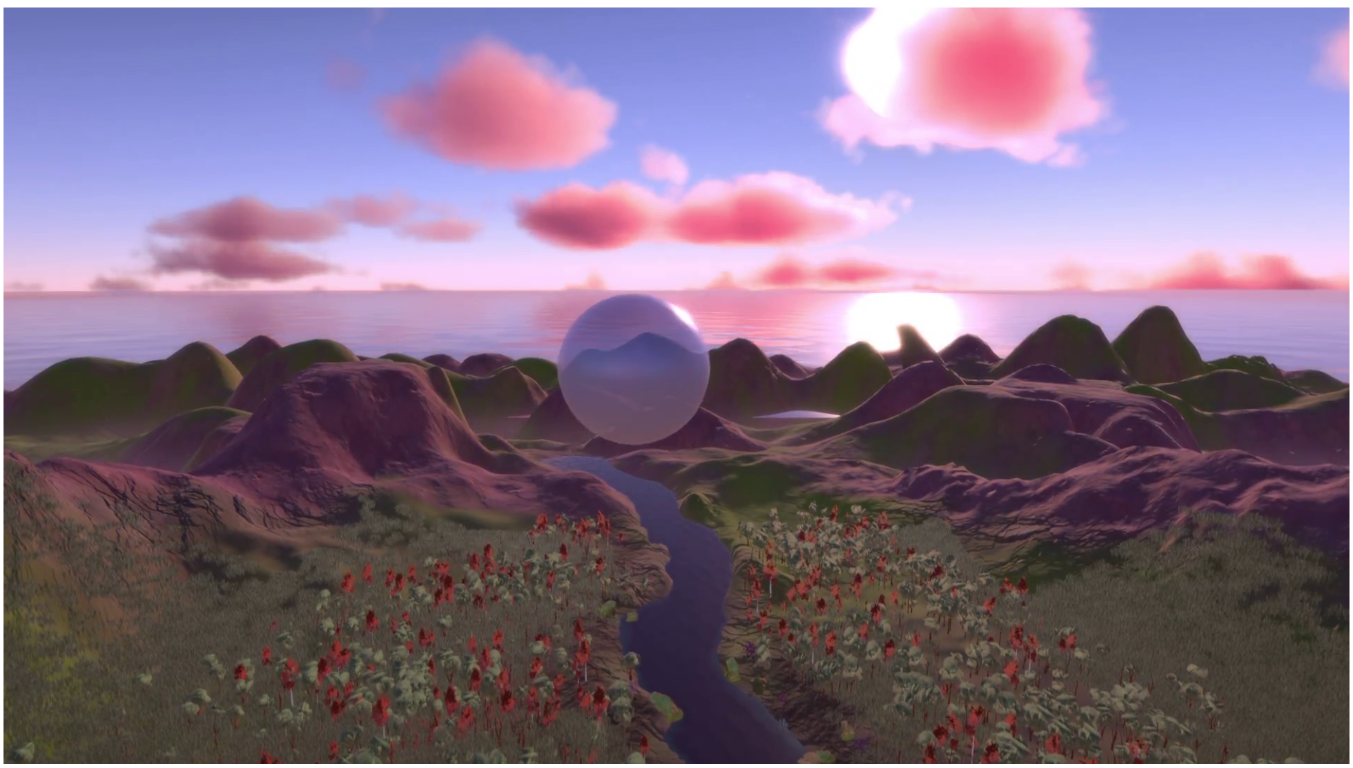

Figure 1: The designed experience: the bubble avatar responds to the user's breath, expanding and contracting while soaring into the sky.

ABSTRACT
This work explores utilizing representations of one's physiological breath (embreathment) in immersive experiences, for enhancing presence and body awareness. Particularly, embreathment is proposed for reducing claustrophobia and associated negative cognitions such as feelings of restriction, loss of agency, and sense of suffocation, by enhancing agency and interoception in circumstances where one's ability to act is restricted. The informed design process of an experience designed for this purpose is presented, alongside an experiment employing the experience, evaluating embodiment, presence, and interoception. The results indicate that embreathment leads to significantly greater levels of embodiment and presence than either an entrainment or control condition. In addition, a modest trend was observed in a heartbeat detection task implying better interoception in the intervention conditions than the control. These findings support the initial assumptions regarding presence and body awareness, paving the way for further evaluation with individuals and situations related to the claustrophobia use case.

CCS CONCEPTS
• **Human-centered computing** → *Interaction design*; *Empirical studies in interaction design*; **Empirical studies in HCI**; **Mixed / augmented reality**; **Interactive systems and tools**;

KEYWORDS
embodiment, presence, respiation, sense of control, agency, embreathment, breathing, negative cognitions, claustrophobia

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1 INTRODUCTION
The use of physiological signals in virtual environments is gaining popularity in numerous fields of application, due to their ability to increase the experience's realism [40]. A number of different measures are employed, including (but not limited to) electroencephalogram (EEG) [33], electrocardiogram (ECG) [22], Electrodermal activity (EDA) [37], Electromyography (EMG) [50], and respiration (breathing). Breathing, similar to other physiological signals, is often employed in virtual reality to change the attributes or properties of a visual scene through biofeedback, and is incorporated in numerous interactions in VR [15, 19, 32, 34, 40, 41, 47] and AR [20, 46].

Breathing is unique in that it is one of the only bodily signals voluntarily controlled at will [30, 39]. For this reason, some studies have utilized it for enhancing embodiment in a virtual avatar [14, 31], defined as the sense that the avatar's processes are the properties of one's own body [25]. The sense of embodiment provides the foundation for one's experience of presence in virtual reality [25], which is the feeling of actually "being there" within the virtual spatial environment [25]. It is commonly accepted that the sense of embodiment is composed of three main factors: sense of self location, sense of agency, and sense of ownership over a virtual "body" or avatar [25]. As such, we believe virtual representation of physiological signals can be a strong link between a virtual "body" and one's physical body signals, enhancing embodiment by increasing awareness to one's body. Specifically, due to the ability to control one's breath, the simple representation of it (embreathment) may epitomize the dimension of agency .

In this study, we wish to propose leveraging the unique attributes of breathing for enabling one's sense of control and agency in circumstances and conditions in which one's ability to act is restricted. Moreover, we suggest that an intervention based on this notion could potentially be highly effective for relief in conditions such as claustrophobia, where embreathment can be employed for decreasing one's perceived loss of control, feeling of entrapment and sense of suffocation.

Claustrophobia is a condition often attributed to the negative cognitions of trappedness (or restriction), loss of sense of agency [43], and feeling of suffocation [35, 38, 45]. Gothic and Dystopian novels often incorporate elements of claustrophobia in the horrific experiences of their characters, and yet claustrophobia is a terror-inducing harrowing reality for over ten percent of the adult population [45], meeting it's sufferers in extreme circumstances such as medical treatments, occupational settings and sports, as well as mundane circumstances such as flights and elevator rides. Due to its high prevalence and debilitating nature, copious methods of treating or reducing claustrophobia are being explored, in virtual reality as well. Most of these methods represent forms of exposure therapy (see [4, 5, 9, 36] for examples) or simple distraction [21] rather than crafting an interaction to address the specific negative cognitions associated with claustrophobia in real time as proposed in this study.

Another aspect explored in this work is the element of interoception. Interoception is the sense of one's bodily condition [13], and is known to be the result of both top down and bottom up effects [3, 17]. Since embodied cognition is thought to be mediated by interoceptive awareness [24], we suggest that when a physiological signal is represented in virtual reality, enhanced interoception would be associated with an enhanced body awareness. This body awareness is not only important for enhancing embodiment as described above, but may also be specifically meaningful for the case of claustrophobia, in assurance of one's breath and their control over it.

To this aim, we developed and evaluated an experience (see Figure 1 and supplementary video) designed to enhance presence by way of embodiment, and interoception, in a scenario built to

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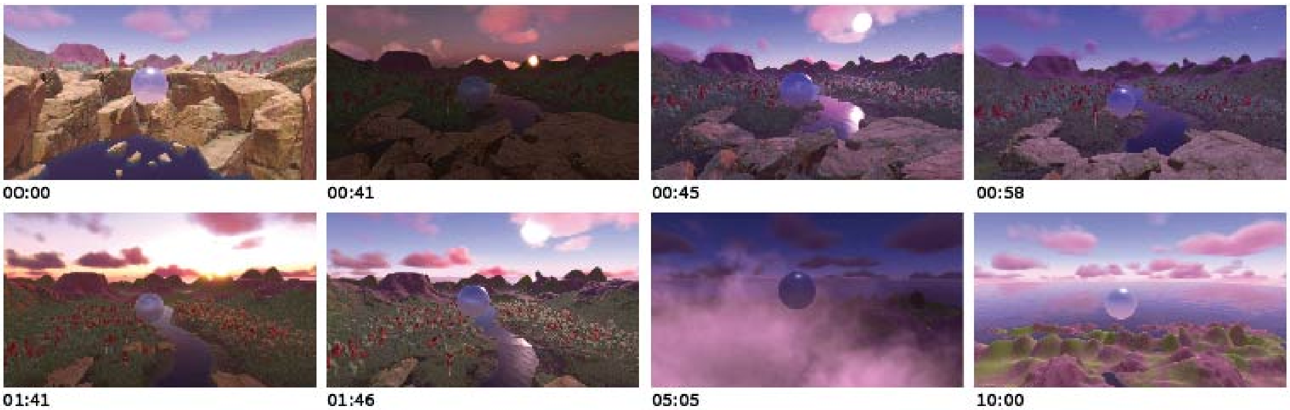

Figure 2: Snapshots from the experience, demonstrating the progression over time and the various design elements.

counter perceived loss of control, restrainment and suffocation which comprise the claustrophobia experience. In this work we evaluate the ability of this experience to enhance embodiment, presence, and interoception using embreathment, as a gateway to future work that could benefit those suffering from claustrophobia and similar conditions.

2 DESIGN AND IMPLEMENTATION

The design for this experiment (see supplementary video), is one of a bubble soaring to the sky from a body of water. The bubble reacts to the user's breath in two ways: by expanding and ascending upon inhaling while contracting and slightly descending when exhaling - creating the effect of ascending over time. We chose to design the experience for projection on a screen rather than through a head mounted display (HMD) with the understanding that such implementation would be more relevant for applying in various relevant use cases for claustrophobia in real-world, everyday circumstances, which are often confined spaces that are less compliant and practical for the use of HMDs such as elevators, airplanes or specific medical or work environments.

2.1 Design Guidelines and Choices

The experience was implemented in collaboration with a professional visual artist who was given design guidelines and feedback from the research team, in an iterative process that involved an ongoing dialogue. The experience was initially defined as one meant to counter or mitigate the experiences of loss of control, restriction and suffocation, commonly associated with claustrophobia.

The following guidelines were originally defined for the interaction, and later underwent fine-tuning and refinement: One or more elements in the environment will reflect the user's breath; The representation of breath must be met with direct feedback (eg. illumination increases and decreases with breath), but can also be a representation of a "processed signal" feedback (eg. a color change controlled by the mean breath rate) or as an accumulative feedback (one that develops over the duration of the experience); The experience should encourage longer, deeper breathing, with an emphasis on extending exhalation [23] by providing rewards in the form of satisfying interactions that support relaxation; We envisioned the elements in the environment being open to the user's subjective interpretation, possibly by making use of minimal, abstract, ambiguous elements and use of transparency or blurred objects boundaries; The environment should feel safe; The environment should convey optimism and positivity - be well lit, use bright colors and a minimal palette. The environment design was driven by the positive benefits and psychological effects of nature on physical and mental health and wellbeing [6, 12]. These benefits have been shown to be applicable to nature as represented in VR as well [8]. Specifically in this case, a 'blue space' design was employed that incorporates a lake or body of water into a natural scene. Prior research has correlated such blue spaces with lowered psychological distress and positive affect [7, 48].

Based on these guidelines, a translucent non-anthropomorphic round avatar in the shape of a bubble was chosen as the embodying, embreathed, element. The choice of the bubble as an object for embodiment, afforded a stronger symbolic representation of breath as opposed to an avatar with human-like features. While embodiment in an avatar is often in realistic, anthropomorphic figures [14, 26], research indicates that anthropomorphism is not crucial for induction of an illusion of body ownership [28, 49], and the avatar need not have a human-like appearance to produce meaningful interaction [1], such as for eliciting embodiment [16]. Over-realism with respect to avatar appearance has even been correlated with "creepiness" associated with the uncanny valley effect [28]. The feedback mechanism chosen involved a direct feedback of the bubble expanding and contracting similar to the natural respiratory motions of the user's lungs. An accumulating feedback mechanism was also implemented - the bubble ascending when exhaling and moderately descending when inhaling - creating the effect of the avatar consistently soaring upward, progressing further and further away from the land surface and up into the sky. This feature was designed for encouraging longer and deeper breathing, with an emphasis on extending the exhalation, rewarding the user with progress in the experience, and revealing of the view, with the ratio of presented land to sky shifting throughout the progression of the scene. With the aim of enhancing the feeling of advancement and attentiveness to the scene over time, two visual elements were incorporated in the experience (see Figure 2). The first is the daily cycle of a sun, rising and setting while creating fluctuations of light and dark and creating an oscillation from day to night. The second visual element is layers of clouds placed at different heights.

2.2 Technical Implementation

The implementation of the experience was executed using the Unity game engine. Respiration readings for the real-time feedback were obtained with a Plux Biosignals respiration belt (PZT), connected by Bluetooth to OpenSignals, an open source dedicated software for real-time biosignals recording and visualization. The acquired physiological reading was sent in real-time using the Lab Streaming Layer (LSL) protocol. This stream was received by a Python code which mapped the values read to a range between 0.2 and 0.8. The mapping included a calibration of the range to account for measurement range differences between participants and over time. The calibration was done by calculating the mean values of min and max values for each breath over a 10sec window. This mean min-max range was then mapped to a range of 0.2 to 0.8. Another function regulates the rate of change in the min and max values used, so as to avoid any sudden changes in the avatar's response behavior.

The mapped values between 0 and 1 were streamed to MAX/MSP via User Datagram Protocol (UDP). In MAX/MSP the data undergoes basic signal processing, calculating a running average and smoothing with linear interpolation. The processed signal was then relayed to Unity via UDP. Unity inherent C# scripts were used for receiving the samples and manipulating the objects in the virtual environment. The avatar changes its size from 20% to 120% of its original size, scaling it by $(1.2 - breathVolume) * breathVolume$. The ascending and descending mechanism was programs so that for each frame the direction is set by the $CurrentBreathVolume - PreBreathVolume$ value sign, and the change in latitude per-frame was determined by $breathVolume * 2.5[cm]$ in a 20fps rate. For the environment, a day-night cycle was applied based on a time cycle of 2min for a full cycle (5sec = 1h). Clouds were located in 2 layers at the heights of 900 and 1,700 meters.

3 METHOD

3.1 Participants

Fourteen participants (12 female, 2 male) were recruited for this experiment through the University's SONA credit system. All participants had normal or corrected to normal vision. Participants had no known hearing/balance impairments or neurological conditions. This study received full ethics approval from the University's Institutional Review Board (IRB).

3.2 Experimental Setup and Design

The experiment was conducted in a soundproof room. Operation of the study was carried out from a separate adjacent control room. Visuals were projected onto a screen covering one of the walls of the cube shaped room. Participants were seated in the center of the experiment room facing the screen (see Figure 3).

In order to separate the effect of an organic body signal and the ones of a controlled body signal for supporting agency, we compared a control condition with an entrainment (a rhythmic simulated breathing pattern) and embreathment condition (responsive to/mapped to their breathing). Both of which can be considered to increase one's sense of embodiment [31].

We used a within participants study design. Conditions were presented in pseudo-random order. Before the first condition, participants were guided to breathe deeply. The conditions were:

- Embreathment – the avatar's physical movements within the virtual environment were mapped in real time to the participant's breathing.
- Entrainment – the avatar's physical movements within the virtual environment rhythmically simulated natural breathing patterns. This was implemented using the recorded breathing signal of a pilot run participant.
- Control – the avatar's physical movements within the virtual environment were not correlated with breathing patterns neither real nor simulated. In this condition, the bubble maintained its size and kept rising at a constant speed.

Figure 3: Staging of the experiment setup: the participants sat in the center of the room connected to a breathing sensor, facing the projected visual scene. A keypad was placed on the table next to them for the heartbeat detection task

A number of subjective measures were employed. The preliminary embodiment short questionnaire (pESQ) [18] consisted of six questions and the holistic presence questionnaire (HPQ) [44] consisted of five questions scored on a Likert scale. The pESQ was chosen due to its specifically incorporating all three of the embodiment factors. The HPQ was chosen due to its being designed to measure presence in augmented reality and mixed reality, as opposed to most presence questionnaires that aim to assess presence in virtual reality alone. In addition, we employed a comparative physiological measure, the mental heartbeat detection task [29], which is based on a comparison between one's reported heartbeats per a given time frame as compared to their objective heartbeat measurement as acquired using ECG. The aims of using the heartbeat detection task were twofold, first of all we wished to utilize the test as an objective measure of interoception, and second, it is particularly relevant for testing body awareness, a measure which is relatively underrepresented in the pESQ, with only one question assessing the factor of body ownership. ECG recordings were obtained using the same Plux Biosignals and OpenSignals system used for acquiring the respiration signal, and participants' subjective heartbeat detection was obtained by their pressing a keyboard key whenever they believed they sensed a heartbeat. Key presses were recorded as timestamps on the OpenSignals logging of the ECG itself. Finally the participants were asked to freely describe in a few sentences what they thought they experienced.

4 RESULTS

4.1 Embodiment

We initially calculated the mean ratings for embodiment on the pESQ (Cronbach's α: 0.789), and then performed non-parametric Wilcoxon signed rank tests at 5% significance between the conditions. We found that embodiment ratings in the embreathment condition were significantly higher (mean (m)=3.31, standard deviation (std)=0.70) than ratings in the entrained condition (m=2.37, std=1.07, Z = -2.198, p = 0.014, one-tailed) and the control condition (m=2.43, std=0.95, Z = -2.553, p = 0.005, one-tailed). Embodiment ratings were not significantly higher in the entrainment condition than in the control condition (see Figure 4 left).

4.2 Presence

We initially calculated the mean ratings for presence on the HPQ (Cronbach's α: 0.874), and then performed non-parametric Wilcoxon signed rank tests at 5% significance between the conditions. We found that presence ratings in the embreathment condition were significantly higher (m=3.29, std=1.02) than in the entrained condition (m=2.61, std=0.92, Z = -1.749, p = 0.040, one-tailed) but not the control condition, though a trend towards higher ratings in the embreathment condition was observed (m=2.84, std=1.14). Presence ratings were not significantly higher in the entrainment condition than in the control condition (see Figure 4 right).

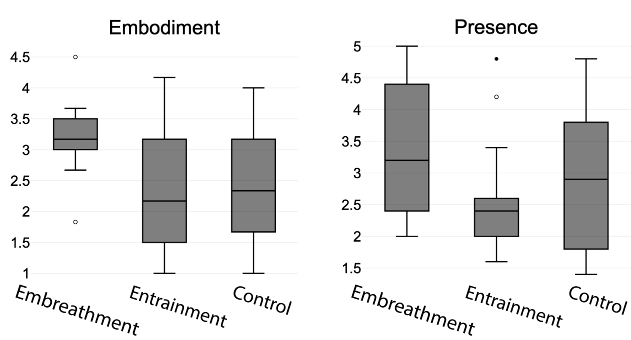

Figure 4: The embodiment and presence ratings in all three conditions. Boxplots represent medians, and variability of the ratings.

4.3 Heartbeat detection

The heartbeat detection task was conducted only on the first condition in which the subject participated, to prevent repetition effects, and was compared between subjects. The score on the heartbeat detection task was calculated as the number of perceived (reported) heartbeats during 3 minutes of ECG signal acquisition divided by the heart beats measured by the ECG. One participant's physiological data was corrupt and could not be analyzed and was therefore excluded from the analysis. Group level analysis or tests of statistical significance were not conducted due to the small sample size comprising each of the conditions separately. Yet the results of a subject specific analysis indicated a trend towards a higher heartbeat detection rate during the embreathment condition, followed by the entrainment condition. Another interesting trend noted was that subjects in the embreathment condition showed lower mean ECG rates compared with the other two conditions (see Figure 5).

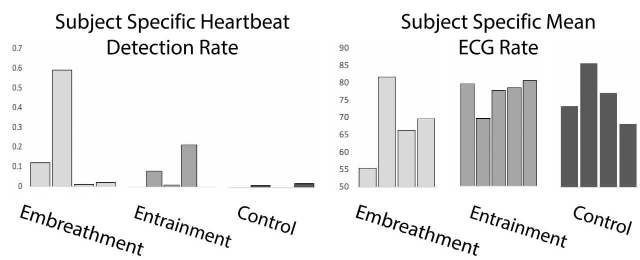

Figure 5: The subject specific heartbeat detection and mean ECG rates as measured on the heartbeat detection task.

5 DISCUSSION

This study employed the physiological mechanism of breathing, one of the few bodily signals capable of volitional regulation, for increasing one's agency and body awareness. These findings encourage us to believe that embreathment could be utilized even under restricting conditions for reducing associated negative cognitions such as the feelings of restriction, loss of agency and feeling of suffocation, associated with claustrophobia. More specifically, this study has shown that embreathment can enhance immersive experiences, leading to a greater sense of embodiment, alongside an increased sense of interoception. We have shown that a responsive respiration mechanism, serves as the basis for these findings. In addition, this study strengthens prior research showing that embodiment and presence can be induced in non-anthropomorphic avatars.

Moreover, an observed trend towards decreased mean ECG rate was found to be of interest, as lower heart rate is often associated with subjective assessments of feeling relaxation, another factor that could be beneficial in mitigating claustrophobia and other similar conditions [2, 10].

Backing the findings subjectively with regard to embodiment is feedback received from the participants. One participant described their experience of the embreathment as "I think that I experienced having some kind of control over the environment on the screen by my breathing". Another interesting theme arose from the open ended questions, regarding the natural elements integrated in the experience. Feedback from the participants indicated that the day/night cycle seemed to serve as a form of representation of breath in itself, to which participants, particularly in the control condition, attempted to relate to. This impression is conveyed in reports such as "I experienced a scenario in nature throughout the day and night and saw how it affected my body by seeing the scenario repeat itself". This may be due to the natural association of day/night cycles with the natural circadian bodily rhythms. This may also align with research indicating that circadian rhythms influence breath [42], a fact that may affect the user's experience of a system with this representation. Moreover, one can speculate that this impression came about mostly in the control condition, due to people's known cognitive inclination to interpret and find meaningful patterns in information [27].

Despite the relatively small and homogeneous sample size, these findings serve as a successful initial proof of concept for this potential use of embreathment. The work demonstrates the design and conceptualization of an embreathment experience aimed towards a particular use case in mental health, that of claustrophobia. By doing so, it further puts forth the significance of breathing in case-specific experience design-as-intervention to serve the unique needs of individuals dealing with psychological conditions. It contributes particularly by exemplifying an implementation process for such experiences. Future work should explore implementations of such immersive experiences in various use cases and scenarios with respect to reducing the sense of claustrophobia and other negative cognitions. Such scenarios will include new challenges such as multi-user interactions and need for different measurement devices. Moreover, this can be explored further with a population of individuals that suffer from claustrophobia, and the experience itself can be expanded in various ways. Particularly, we aim to incorporate other physiological signals, and additional dimensions of sensory information such as audio, particularly since multisensory integration is known to be tightly associated with increasing embodiment and presence in virtual reality [11].

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