JeL: Breathing Together to Connect with Others and Nature

Ekaterina R. Stepanova,*[*] John Desnoyers-Stewart, Philippe Pasquier, Bernhard E. Riecke
School of Interactive Arts and Technology, Simon Fraser University, Vancouver, Canada
erstepan@sfu.ca, desnoyer@sfu.ca, pasquier@sfu.ca, ber1@sfu.ca

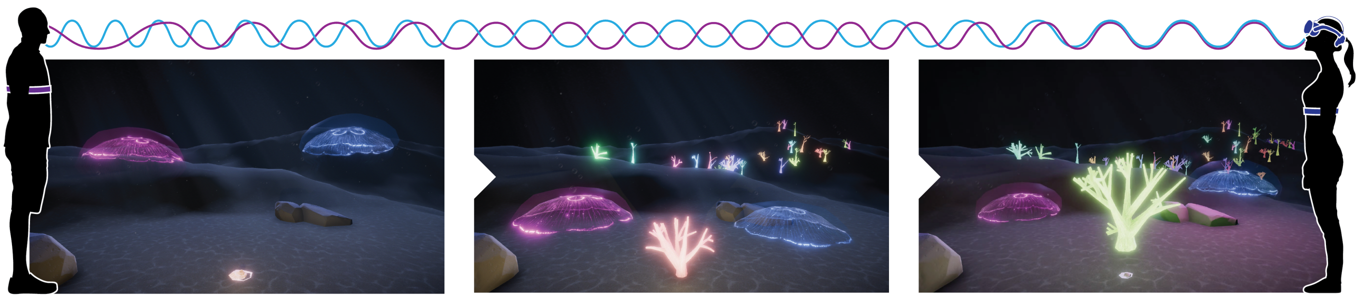

Figure 1. Diagram of progression through JeL. The jellyfish represent the two immersants' individual breathing while the growing coral in the center is fed by their breathing synchronization. In the background, the interaction of several immersants populates the coral reef.

ABSTRACT
Bio-responsive immersive Virtual Reality can transform our interactions to bring awareness to our physiological rhythms fostering connection with our bodies, each other and nature. JeL is an immersive installation that aims to foster a feeling of connection through the process of breathing synchronization. Two immersants synchronize their breathing to fuel the growth of a coral-like structure that, together with the interactions of others, populates an initially empty coral reef. JeL is designed to support an intimate connection between users and with nature, sending a message about our collective capacity to care for the environment. JeL is an installation and research platform for exploring breathing synchronization and its effect on the feeling of connection. It was well received at a digital art festival where participants were able to relax and synchronize using the installation. Reflection on our design process and observations provides insights for the development of systems that promote connection.

Author Keywords
Feeling of Connection; Interpersonal Synchronization; Virtual Reality; Installation Art; Bioresponsive Systems; Breathing Biofeedback; Generative Systems; Ecopsychology

[*]The first two authors have made an equal contribution

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CCS Concepts
•**Human-centered computing → Virtual reality;** *Collaborative interaction;* Field studies; Interface design prototyping;

INTRODUCTION
Virtual Reality (VR) technology encompasses any media that allows users to have an experience of being present in a synthetically generated reality, including desktop computers, projection screens, and Head-Mounted Displays (HMDs) [92]. Due to its ability to allow users to escape the real world it is often criticized for being isolating and potentially decreasing the feeling of social connection. However, VR is not inherently isolating. We, as a community of researchers and designers, have a responsibility to ensure that we create applications that foster human connection and enrich our lives, as stressed by "the father of VR", Jaron Lanier [42]. Indeed, the medium of VR presents a unique opportunity for the design of novel, emotionally profound experiences that can improve well-being and foster increased social connection and connection with nature (for reviews of VR applications for positive change see [39, 76, 87]). The immersive potential of VR allows us to create experiences that could not otherwise exist, and to focus the user's attention on aspects of their interpersonal interaction that normally remain unnoticed, including physiological rhythms.

VR applications designed to foster the feeling of connection generally approach it in two distinct ways: (1) by evoking a profound sense of connection in an individual to the whole world through e.g., a self-transcendent experience, or (2) by allowing multiple users interact in a social VR application. Experiences such as self-transcendence can provide a feeling of interconnectedness with the whole world [34, 44, 45, 90, 105], including nature and all of humanity. VR presents an opportunity to make such experiences more accessible. Indeed, a number of VR experiences using inspiration from nature were able to elicit a particular self-transcendent emotion—awe [12], and a feeling of connection in immersants [10, 11, 71, 91]. Social VR applications are still somewhat sparse, and often do not go beyond chat rooms, such as VR Chat [2] and AltSpace VR [1]. An example of a promising commercial VR game that delivers a unique experience of social connection is "Where Thoughts Go" VR [77], where immersants become a part of a large anonymous community leaving and discovering personal messages in a virtual space. However, there seem to be few, if any, VR experiences and research that combine social VR with the goal of eliciting profound experiences of connection to others and nature.

Informed by transformative experience design [38] and research on self-transcendence and mindfulness meditation [44], we present our system—JeL—that builds on both approaches for supporting connection through VR. JeL features an underwater virtual environment inspired by nature and designed to elicit the self-transcendent emotion awe (Figure 1) and create stronger awareness of our bodily functions through a breath-based interaction . JeL is also designed as a shared social experience, where two participants interact by collaborating. To combine the above two approaches and foster a feeling of connection, we are implementing two mechanisms of interaction: biofeedback and interpersonal synchronization.

Biofeedback can bring awareness to physiological state and activity, promoting connection to the body, mindfulness, and affect regulation. Consequently, biosignals (e.g., respiration, heartrate, and Electroencephalography (EEG)) are becoming increasingly popular in experience design, allowing for novel embodied forms of interaction [84]. Such interactions successfully complement affective experiences in applications aimed at supporting mindfulness and improving well-being through stress reduction [25, 65, 68, 80, 100]. Biofeedback can also give access to personal and normally hidden information about the state of the person one is interacting with [33, 102], which can contribute to increased understanding, empathy, intimacy, relatedness, and togetherness [9].

The feeling of connection between two people is correlated with their interpersonal *synchronization*. When two people are interested in interacting with each other, they often synchronize their movement and physiology, amplifying their feeling of social connection and improving the interaction [51, 62, 74]. For example, we will often match our body posture to the person we are talking to, or respond with a smile or a frown to others smiling or frowning. This effect is described by the phenomenological concept of *intercorporeality* [54], which explains how aligning our bodily states with others allows us to further understand and connect with them. Engaging in an activity that encourages synchronization (e.g., rowing, dancing or singing in a choir) leads to increased feeling of social connection and pro-social outcomes (for reviews, see [16, 20, 51]). Kim [36] argues that digital media presents a novel opportunity to form intercorporeal relationships mediated by technology. Yet, technology often obstructs our ability to engage in embodied social interaction. Despite the embodied potential of VR and biofeedback technology, few applications utilize this mechanism of synchronization to support positive affective experiences promoting the feeling of social connection.

Intercorporeal experience can also allow us to develop an affective connection to nature. Feeling connected with nature makes us care more for the environment and supports well-being [31, 60, 83]. While there are several VR applications aiming to promote connection to nature (e.g., [3, 91]), the potential of bio-responsive technology and synchronization as a mechanism for establishing this connection has not been sufficiently explored.

We designed JeL to facilitate social connection through gamified breathing synchronization. The use of a virtual environment inspired by a marine ecosystem aims to support connection to the important creatures ordinarily hidden underwater. The name of the system, **JeL**, is a play on the words "**Je**llyfish"+"**L**-System"(used for coral generation) and the phrase "to **jel** with someone", indicating the environmental and social connection motivations for our system along with its technical function.

Next, we discuss the development of the system, the design inspiration and decisions made in the process, as well as an initial evaluation of the system during a public exhibition. A more comprehensive evaluation with the assessment of the system's capacity to increase connection with others and nature will be reported in upcoming publications. Through this work we aim to answer the following research questions:

How can a bio-responsive immersive system be designed to promote the feeling of connection through the use of breath synchronization? Does the use of an immersive system which requires collaboration between people using breath encourage synchronization?

RELATED WORK

JeL builds upon a wide range of overlapping areas. Our research seeks to apply Boden's concept of *combinational creativity* [8] to find new areas for research by combining practices from a broad set of distinct areas accentuating the exploratory nature of the work. Rather than focusing on the shortcomings of each related work within their own domain, we sought to use those works as a foundation onto which we could combine concepts to produce work that crosses disciplinary boundaries. Our inspiration is primarily drawn from research and interactive systems in three major categories: bioresponsive systems, synchronization systems and systems promoting connection to nature. Building on this research we created JeL—a bio-responsive immersive experience encouraging two participants to synchronize their breathing and collaborate to grow a virtual coral reef, fostering their feeling of connection with each other and with nature.

Bioresponsive Systems

Bioresponsive systems refer to interactive systems which take biosignals (such as respiration, heartrate, brainwaves, skin conductance, etc.) as input and produce a responsive output reacting to these signals which allows for alternative physiological modes of interaction. Respiration [65, 68, 80, 89, 100, 101], heart rate [24], skin conductance [25] and EEG [5, 93] have been effectively integrated in VR as a form of interaction promoting mindfulness and relaxation. While the majority of bio-responsive VR systems target the regulation of arousal and awareness, some attempt to detect specific emotions [23], reduce chronic pain [25] or promote empathy [40].

Interaction in VR through Breathing

Respiration was used for bioresponsive interaction in VR to create affective, meditative or relaxing applications. While there are many bioresponsive breathing regulation applications for desktops or mobile apps (e.g., [63,64,69,85,88]), VR aims to deliver a more immersive and affective experience, with several examples of breathing interaction throughout the history of VR beginning with *Osmose* by Char Davies [14]. This historically significant VR installation incorporates breath for interaction with an abstract virtual environment that enables a reflexive exploration of oneself as an embodied consciousness in space. More recently, *Respire* [68], is a VR installation that lets immersants float near the surface of an ocean, where their breath controls their position (depth) in water and effects a generative soundscape. Another underwater VR system, *DEEP* [100], is a VR game for kids with anxiety that requires them to navigate using their breath in a colorful underwater environment, gamifying deep diaphragmatic breathing. While in *Osmose*, *Respire* and *DEEP* breathing is mapped to immersant's position, usually based on a diving metaphor, in other systems it is mapped to elements in the environment. For instance, *Life Tree* [65] is a VR game that teaches users breathing exercises, allowing them to bring a tree to life by executing correct breathing pattern. A less direct breathing mapping is used in *Inner Garden* [80], a mixed reality game designed for mindfulness in which participants form a landscape in a sandbox that they can then explore in VR. Biofeedback of their heart-rate and breathing determines the weather conditions in that world. These systems support breathing regulation to reduce stress or enable mindfulness by connecting immersants to their physiological state. JeL takes inspiration from these systems by creating a bio-responsive interaction that encourages slow, deep breathing and connection to one's body.

Interpersonal Physiological Connection

In addition to providing a stronger connection to oneself, bioresponsive systems can also be used to provide a means for interpersonal physiological connection, intimacy and empathy. *Breathtaking Journey* [40] is a multi-sensory VR narrative experience encouraging empathy for a refugee's perspective as they try to flee their country. The immersant is placed in the shoes of a refugee hiding in a truck where they must hold their breath to avoid being noticed, giving them a glimpse into the refugee's experience. Although this installation connects the immersant to a fictional character, the principle of adopting another's physiological state to understand their inner state can similarly apply to communication with another person.

Displaying physiological information to others can enable communication of one's affective state and make individuals feel more connected (e.g., [28,56,103]). *Pulse Corniche* [47] uses heartbeat biosensing to connect an individual to their community by displaying their pulse in the sky. Reciprocal physiological communication between two people over distance has been used to support long-distance relationships [27,46]. For example, *BreathingFrame* [37] is a soft, tangible photograph frame designed for couples in long-distance relationships. When one partner breathes in, their partner's photoframe inflates, communicating their breathing in a tangible form. A similar approach was taken in *Breath is to be Perceived* [94] which uses two sofas with inflatable pillows. When talking with a partner, the pillows inflate and deflate corresponding to other's breathing. Similarly, JeL is designed to give participants access to the normally obscured physiological state of the other person, allowing for a deeper connection.

Synchronization Systems

The main motivation of JeL stems from research on the effects of interpersonal synchronization on social connection [51]. Synchronization is most frequently studied in terms of movement synchrony. While physiological synchrony receives less attention, it also correlates with movement synchrony [13].

Movement Synchronization

Studies show that synchronous movement increases affiliation [32], success in cooperative tasks [99], compassion and inner group altruism [98], and pro-social behavior towards out-group members [73]. Moreover, the effect of synchronous movement increases when participants share intentionality [72]. Thus, in JeL, we included a shared task for participants, seeking to intensify the effect of synchronization.

The social benefits of synchrony persist in mediated interaction as well, e.g., when participants synchronize movement with a pre-recorded video, thinking that they are synchronizing with another participant in real-time [41]. Even when the other is represented only through sound they are perceived as more trustworthy when synchronized [43]. The only example of deliberate synchronization interaction in VR is Tarr et. al. [95]. This study ultimately replicates a standard in-lab synchrony study in VR: participants perform arm movements along with virtual avatars that either synchronize with the participants or do not. Participants reported that they felt more connected to those that synchronized with them, supporting that synchronization can be as effective in VR as in real life.

Bioresponsive Synchronization

Physiological signals such as breath, heart rate, skin conductivity and even brainwaves have been shown to correlate between individuals and have been associated with movement synchrony as well as positive outcomes of synchronization [20, 29, 57, 59]. There are a number of multi-user interactive systems developed using biosignals. These primarily include systems which communicate the users' breath or heartrate to foster connection between people; however, to the best of our knowledge, none have been implemented in VR.

While there are several artistic works exploring the relationship between inter-brain synchronization and human connectedness [19], breathing synchronization is less commonly used. An interesting artistic example of movement to breath synchronization integrated into the interaction is observed in *Breathless* [7]. Here, one participant rests on a swing while a second one uses their breathing to push the swing. To promote breathing synchronization, *Breeze* [22], a mobile app, visualizes respiration recorded from a pendant. While designed for synchrony, *Breeze* does not provide feedback for the level of synchrony. One example of explicit biofeedback of synchronization is *ExoPranayama* [58], a yoga experience created with the use of the *ExoBuilding* system [82]. This portable, projection-based yoga studio consists of a tent that oscillates with one's breathing and a projection of an "Om" sign onto the tent that brightens when two yoga practitioners breathe in sync. *ExoPranayama* supports yoga practice which already includes some level of breathing synchronization. *In the Same Boat* [79] is a prototype video game that gamifies breathing synchronization by requiring players to synchronize their breath to successfully paddle a boat down a river. Breathing synchronization between multiple users was also employed in the art installation *Exhale* [81]. In *Exhale* participants wear skirts with small fans, which allow them to feel the 'breath' of the other person on their legs. When breathing is synchronized, LED lights on the skirts glow. This installation created a meditative and intimate interaction between strangers. Building on the approaches in these systems, in JeL, we combine the meditative aspects of a breath-responsive art installation with the gamification of biofeedback to encourage participants to synchronize in immersive VR.

Connection to Nature

Art installations can connect participants to nature and the need to protect it. Tamiko Thiel's *Unexpected Growth* draws attention to the dying coral reefs. In this augmented reality piece, corals made from plastic objects, such as flip flops and rubber ducks, grow in response to the viewer's gaze [96]. If the corals are viewed too much they become bleached. Thiel's piece reminds the viewer of the fragility of coral reefs and humanity's involvement in their destruction. VR experiences have been shown to be successful at increasing feelings of responsibility for the environment through embodying cows [3], cutting virtual trees [4], engaging in virtual penguin conservation training [66], exposure to a vivid feedback of one's virtual energy/hot water usage [6], and observing effect of ocean acidification on coral reefs [50]. While some systems aim to promote pro-environmental behaviour by showing the negative effects of our behaviour, others aim to support the positive feeling of connection with nature [3, 14, 91]. As such, VR presents a powerful opportunity for persuasive artwork that can leverage the embodied, interactive nature of VR to connect immersants more deeply and directly with nature and the environmental message encouraging awareness and increased responsibility for the environment.

JeL: a Bioresponsive Synchronization System for Connection to People and to Nature

JeL integrates knowledge from these related works to produce a bioresponsive system for social synchronization. By integrating the personal interactive experiences of VR-based bioresponsive systems such as *Respire* [68] and *Life Tree* [65], the gamification of breathing in *DEEP* [100], and the social synchronization possibilities of *Exhale* [81], we aim to produce a system which connects immersants by exposing physiological signals in a social setting. By using these signals to grow a virtual coral reef, we hope to provide immersants with a common goal around which to collaborate, connecting immersants with important natural phenomena. We hope that by collaborating to produce a natural structure immersants will realize a positive message of their capacity to effect environmental change by cooperating with friends and strangers alike.

SYSTEM SPECIFICATION

JeL consists of a virtual environment viewed by two participants through an HMD or projection, and two breathing sensors used as an inputs for the system (Figure 2). In the virtual environment, participants see an underwater world with two jellyfish and a growing coral reef. The jellyfish responds directly to participants' breathing, while the coral-like structure grows as a result of breathing synchronization between the two participants and adds to the coral reef accumulated through multiple interactions. The system gamifies synchronization through the collaborative production of coral-like forms. It responds to and encourages the synchronization of immersants physiologically, enabling a shared experience of internal states and encouraging a sense of social connection. A video showing the system in operation can be seen here. [1]

Design Process

Developing the virtual environment and deciding on the mappings for the interaction followed an iterative and experimental design process. We have significantly revised and extended our initial prototype [17] in preparation for exhibition. Several methods for mapping the parameters were rapidly prototyped to establish what worked best through experimentation.

Virtual Environment and Inspirations from Nature

Each immersant has a corresponding jellyfish agent in the underwater virtual environment. Moon Jellyfish (Aurelia Aurita) were chosen for their simple and elegant form, they move slowly and have been previously used in applications to evoke relaxation [86, 89]. Many jellyfish also feature bioluminescence [55] which is used in the experience to provide immersants with clear and compelling feedback of their breathing. The synchronization between participants in JeL grows a coral that populates a reef throughout the exhibition of the system. We chose the coral reef as a representation of synchronization due to its colourful beauty and to remind participants through the collaborative process of synchronization about our collective stewardship for coral reefs currently facing extinction from rising ocean temperatures [30].

JeL Experience Scenario

JeL has been designed with the aim of evoking a particular user experience in which participants can engage in a positive and collaborative activity where they develop a sense of connection to the other participant and nature. Here we describe how JeL is intended to be used as a public installation. While the experience itself cannot be designed, only be designed *for* [67, p.12], the following is an ideal experience which we aimed for through our design:

1. *Initial Investigation:* Unsure of its interactive nature, users approach JeL with tentative curiosity. A facilitator offers to help put on a breathing sensor and optional HMD, suggesting that they try to affect the system with their breathing.
2. *Breathing Exploration:* The users experiment with their breathing. After a few moments they notice a relation and

[1] http://ispace.iat.sfu.ca/project/connecting-through-jel/

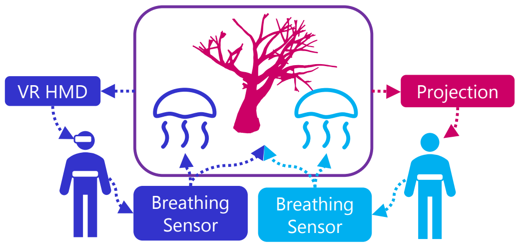

Figure 2. System Diagram

feel some control. This introspective interaction inspires wonder and further curiosity. The hypnotizing movement of the jellyfish and rhythmic sounds of waves synchronized to their breathing make the immersant feel calm and relaxed.

3. *Coral Growth:* Confidently controlling their respective jellyfish, the users play with it. Occasionally they notice an unknown form that begins to light up and grow and the captivating sound of a distant whale song becomes more apparent. As they experiment, they notice it only seems to occur when the conditions are just right.
4. *Aha Moment:* Similar to the Aha effect mentioned by Pachet [61], at some point, the immersants will have an "aha moment" where the connection between the synchronization of their breathing and the coral's growth becomes apparent—The immersants now try to breathe together.
5. *Collaboration:* Aware of the capacity of their collaborative actions to stimulate growth of the coral, the participants are motivated to breathe together. The coral grows faster, producing forms that reflect their synchronization and inspiring a feeling of togetherness through collaboration.
6. *End or Repeat:* After about 2 minutes of interaction the coral is completed. It flies away to join other corals in a reef representing the previous interactions of other participants. The immersants can continue collaborating to grow a new coral, creating more new forms, or end their experience.

Implementation

JeL is implemented in Unity 2018.2.11. The hardware is integrated using the Vive SDK and Lab Streaming Layer (LSL)[2] which recieves data from the sensor via BioSignalsPLUX Open Signals. LSL was used to facilitate the integration of off-the-shelf systems such as BioSignalsPLUX and Bitalino as well as custom hardware using platforms such as Arduino.

The hardware used includes:

- HTC Vive HMD with noise-cancelling headphones
- BiosignalsPlux PZT breathing sensor
- BiosignalsPlux hub, Bitalino hub, or custom Arduino hub
- Video projector (2 m x 3.56 m projection)
- Desktop Computer with NVIDIA GeForce GTX 970.

Inputs and Outputs

Sensing Breathing

Breathing rate is captured using a BiosignalsPLUX Piezoelectric (PZT) Respiration Sensor. Typical of PZT transducers, if breathing is paused then the sensor's output slowly returns to the center point, allowing the sensor to adapt to various body types without calibration. We used this sensor with BiosingalsPLUX and Bitalino hubs to allow multiple users to connect wirelessly. We also developed an implementation that uses an Arduino for streaming data over USB in case of Bluetooth interference which other hubs occasionally suffered from.

[2] https://github.com/sccn/labstreaminglayer

Projection and HMD

We chose to combine projection- and HMD-based approaches for delivering the VR experience of JeL. The projection acts as a window into the virtual underwater scene like the glass wall of an aquarium. On putting on the VR headset, the user enters the underwater space shared with mesmerizing aquatic creatures. We chose the combination of projection and HMD interaction to allow for an easier entry into the experience. Participants can acclimatize to the breathing sensor and the system first through the projection and then put on the HMD for full immersion. Some participants can also choose not to wear the HMD if they do not feel comfortable with it. The HMD allows for deeper immersion by occluding the distraction of the public exhibit space, giving a stronger experience of being submerged in an underwater world, maximizing participants' focus on breathing and their experience. In addition to stronger sensory occlusion of HMD, we rewarded participants for looking around in the HMD with a whale swimming above them, providing the feeling of delightful surprise from this discovery. While the HMD supports deeper immersion, projection provides an alternative form of interacting with VR, allowing participants to be more aware of their surroundings, supporting different participant preferences. Projections also allow the spectators in the exhibition space to observe the interaction, take pictures and decide if they want to partake.

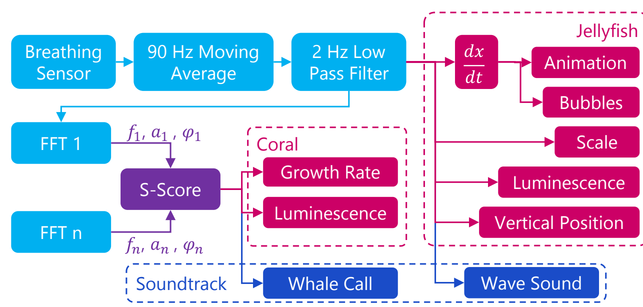

Figure 3. Signal processing diagram

Signal Processing

The signal processing of data is shown in Figure 3. Each sample takes the moving average of values available since the last sample to eliminate noise followed by a Butterworth low pass filter to remove frequencies higher than normal breathing. Normal breathing is around 12 breaths per minute or 0.2 Hz [97] and can increase to as high as 50 breaths per minute (0.83 Hz) [35]. The cutoff is placed at 2 Hz to allow for intentional manipulations of the abdomen. The filtered signal is then converted to the frequency domain using a Fast Fourier Transform (FFT) between 0 to 2 Hz with a bin size of 0.0625 Hz to determine the dominant frequency, amplitude, and phase. The FFT takes a 64 sample sliding window of the input signal at a sample rate of 4 Hz, resulting in a 16 second window.

$$f_r = frequency;\ a = amplitude;\ \varphi = phase$$

$$SyncScore : S = CPK10^{-C_f|\Delta f_r|} e^{-C_a|\Delta a|}$$

$$P = \begin{cases} C_\varphi \frac{cos(|\Delta\varphi|+1)}{2} + 1 & \Delta f_r = 0 \\ 1 & otherwise \end{cases}$$

$$K = \Pi \frac{1}{1+e^{-70(a-0.1)}}$$

Figure 4. Synchrony Score Equation

Measure of Synchronization

The data from each FFT is compared to produce a breath Synchronization Score, S (Figure 4). We developed this formula by experimentation and formative user-tests. While literature on physiological synchrony includes several models used for calculating interpersonal synchrony [20, 29], none of them were suitable for use in JeL. We needed a real-time (as opposed to post-hoc) dynamic calculation, which would allow for the assessment of synchrony while providing a transparent interaction. Once a dominant frequency is detected in both inputs, the sync score is calculated based on the difference in their frequency, amplitude, and phase. The weights (C, C_f, C_a, C_φ) can be varied to adjust the level of challenge and were determined through experimentation.

Breathing Feedback and Mapping

Visual Mapping of Breathing

While many VR breathing applications map breathing to the vertical position of the immersant (i.e. swimming up/down) [14, 68, 100], we opted to externalize the representation, similar to *Life Tree* [65]. This decision was made for several reasons: first, by externalizing the representation, we were able to control several visual parameters beyond vertical position to make the interaction more apparent; second, we hope to create a sense of connection between the immersant and the creature they control; third, we wanted to provide a similar visual representation for each immersant to encourage a feeling of affiliation; and finally, we wanted to minimize visual-vestibular cue conflicts in VR, so that all movements in virtual space are the result of movement through physical space. In addition, this produces a representation that works equally well for projection and HMD.

The inputs from each breathing sensor are mapped as shown in Figure 3. The breathing input is directly mapped to the scale, position, and biolumniescence of the virtual counterpart. The derivative, breathing rate, is mapped to the jellyfish's animation and the generation of particle system based bubbles. The scale of the jellyfish varies in sync with the expansion and contraction of the immersant's diaphragm. The vertical position subsequently increases while the diaphragm is expanded past the midpoint and decreases while it is contracted. The bioluminescence is mapped directly to the breathing sensor's normalized value, providing an additional cue and form of connection. The jellyfish's swimming animation progresses relative to the breathing rate so that the jellyfish's own movements and expansion correspond to those of the immersant's diaphragm. This also synchronizes the jellyfish's swimming with the vertical movement. Finally, while jellyfish themselves do not naturally emit bubbles, we included the familiar metaphor of bubbles being exhaled. This abnormal jellyfish behaviour was included to link the jellyfish's actions to breathing, as though the immersant's own breath was being exhaled out of this creature. In all, this allows for a representation of the immersant's breathing value in an easily understandable format: the creature is breathing, moving, and glowing in sync with the participant's respiration. Both immersants see both jellyfish, with one representing their own breathing and the other, their partner's breathing, facilitating synchronization. They can identify their jellyfish based on its relative position and responsiveness.

Audio Mapping

Participants' breathing and sync score are mapped to audio feedback as shown in Figure 3. Each exhale triggers the sound of a wave crashing onto a reef underwater. The sounds are played separately into the left or right ear, with each ear corresponding to each immersant's relative position (e.g., the breathing feedback from the immersant sitting on the right is played into the right ear of both immersants). The sync score affects the volume of a soundtrack based on a whale call to provide audible feedback of synchronization. These sounds were chosen to provide a calming environment that slowly built along with the progress towards synchronization.

Coral Growth and Synchrony Mapping

Corals in JeL are produced using Lindenmayer Systems (L-Systems), commonly used to model plant life and produce fractal structures from a simple set of rules [70]. For our prototype we adapted the *Procedural Tree* asset available on the Unity Asset Store[3] modified for real-time implementation. We introduced variation through the use of a parametric L-System. This allows the L-system growth to encourage continued interaction through clear feedback while producing variations between each interaction.

Increasing synchronization fuels the growth of the abstract coral. The growth rate and luminescence are based on the synchronization score, providing a fairly direct representation of the level of synchronization. The system growth rate increases exponentially from 0 to 5 mm/s as the dominant frequencies of the signals align and the amplitudes are matched and further increased to a maximum of 7 mm/s by breathing in phase with each other. Our L-system design was informed by previous methods of organic 3D L-system generation [21, 52, 53, 104].

The coral is completed when a predefined iteration or time limit is reached. The limit was set to encourage a 2 minute interaction to manage the high throughput of the busy festival installation. The resulting structure floats up and slowly flies off to the reef in the background where it is planted, populating the virtual reef as more people continue to interact with the system. Each time the growth is completed or a user leaves, the system resets to generate a new structure.

PUBLIC INSTALLATION AND EVALUATION

JeL has two goals: (1) as an artistic installation, it aims to encourage self-reflection and relaxation, and to promote a collective sense of stewardship for nature; and, (2) as a research

[3] https://assetstore.unity.com/packages/tools/modeling/procedural-tree-32907

Figure 5. Two people using JeL at the Fun Palace festival.

prototype it aims to assess the potential of bio-responsive VR to encourage synchronization leading to an increased connection to others and nature. In this first installation of JeL, we evaluate its basic functionality and user experience. The preliminary evaluation is presented to complement the description of the system and to validate that JeL is not just a research prototype but a functional installation well received by the public. This evaluation explores trends in the data and demonstrates areas of investigation that could be pursued further.

JeL was exhibited at a local digital arts festival on June 25th, 2019 at Fun Palace Carnival of Mixed Realities in Vancouver, Canada. This 4-hour long free evening event was attended by a diverse audience of 387 people. Interested visitors could pair up to interact with JeL for about 4-6 minutes (including 2 minutes of interaction and 2 minutes of set-up). Interaction time was constrained by the throughput requirements of the exhibition space. Participants could choose to put on an HMD, or interact only through projection if they don't feel comfortable wearing the headset. An attendant was always present at the installation assisting participants and ensuring their safety and comfort when using the equipment. During the interaction participants were sitting next to each other facing the projection (Figure 5). A total of 63 visitors interacted with JeL while many more observed from a distance. We used this opportunity to perform an initial evaluation and exploratory data collection. We recorded the breathing sensor data during the interaction and twelve participants (7 females, 4 males, 1 undisclosed gender; Age ranges: 18-24: 3, 25-34: 5, 35-44: 3, 45-55: 1) were invited to complete a survey about their experience. The survey included:

1. General user experience and immersion questions
2. Condensed Networked Minds Social Presence Inventory (NMSPI) [26] (mediated social presence)
3. Felt social effect of the installation
4. Draw prize choice (nature vs. other)

The first two measures, (1) and (2), allow us to evaluate our design through understanding specific aspects of participants' experience in JeL. NMSPI tells us how socially present and engaged participants felt and how aware they were of their mediated social interaction. As a bio-responsive system, JeL constraints immersants to attend to each other through their breathing, minimizing other social presence cues, yet it is crucial for participants to feel co-present and aware of each other to develop a sense of connection. Measure (3) taps into the potential effect of JeL on the participants' relationship and connection, and (4) on connection with nature. Given our focus on social connection, we also asked participants if they knew the other person prior to the interaction and how close their relationship was to allow us to better interpret the results. Eight participants had prior relationships that were rated as close on a 0-100 slider scale (Average=90, Min=60) while the other four did not know each other prior to using the system.

First, we report the Survey Results from the 12 participants who voluntarily took the post-experience survey in diverging stacked bar charts [78]. Then, we present an analysis of breathing data from 11 pairs of participants. The raw anonymized data can be found in our local Research Data Repository. [4]

Survey Results

Experiential Descriptions

When asked to provide three adjective describing their experience, the majority of participants described their experience with terms within the theme of relaxation: *"calming"*, *"peaceful"*, *"relaxing"* and *"meditative"*. The second most prominent theme was describing the enjoyment and aesthetic appreciation of how *"colorful"*, *"fun"*, and *"interesting"* the installation was. Finally the third theme indicated that participants were immersed in the challenging task of synchronization describing it as *"challenging"*, *"immersive"* and *"focused"*.

Immersion and NMSPI

In spite of the lively festival surrounding the installation, participants generally reported that they were not aware of other people in the space while using JeL (Figure 7). Only 4 out of 12 survey respondents used the HMD during their interaction, suggesting that JeL was very immersive, even without the HMD. The responses to NMSPI questions (Figure 6) show that most participants were socially present with each other according to each aspect of the inventory, and were significantly affecting each other's experiences. There is a peculiar directionality in participants awareness of other which proved interesting. Participants generally indicated that they had a higher degree of awareness and attention directed towards their partner than they felt was reciprocated. Participants felt that "what their partner did often affected what I did" despite not feeling as strongly that what they did affected their partner.

Perceived Effect on Relationship

When directly asked, several participants felt that the installation had an effect on their relationship with the other person, while some disagreed (see Figure 8). Interestingly, participants who knew each other before the interaction felt that JeL had a stronger effect on their relationship than participants who did not know each other. Participants who knew each other also reported that they felt they learned something new about their partner while strangers did not.

Draw Prize Choice—Connection with Nature

For completing the survey participants were invited to enter into a draw for a prize. We offered a choice between 4 gift cards: 1) Aquarium visit, 2) Science Centre visit, 3) Outdoor

[4] researchdata.sfu.ca/islandora/object/islandora:10821.

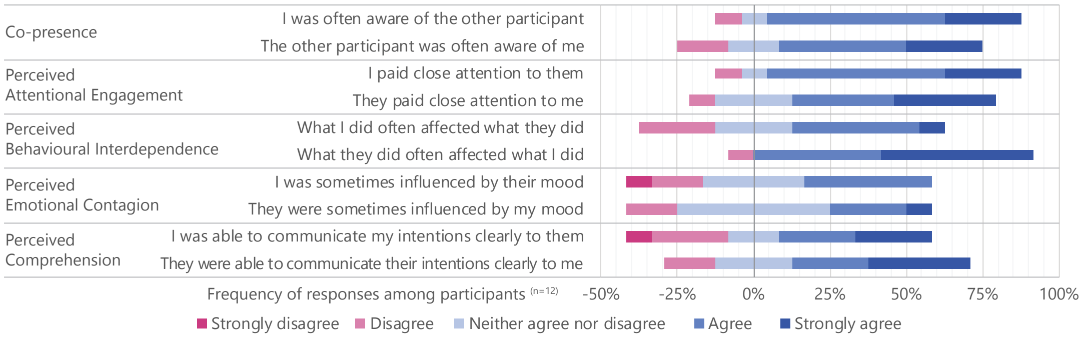

Figure 6. Percentage of participants responding on a Likert Scale to Networked Minds Social Presence Inventory questions.

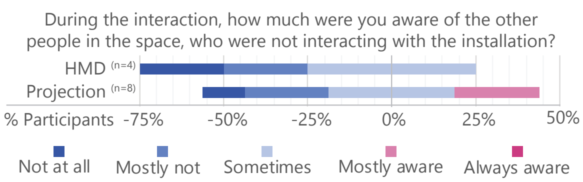

Figure 7. Frequency of responses to immersion question by medium.

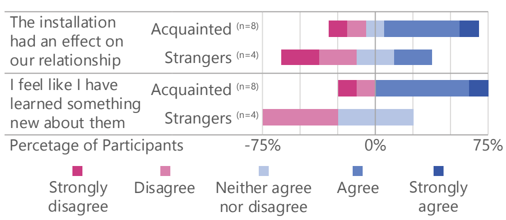

Figure 8. Frequency of responses to Likert relationship effect questions.

equipment store and 4) a popular local retail store carrying a variety of goods. We compared these responses between JeL and another installation – Body RemiXer [18]. Body RemiXer was designed for social connection but not for connection with nature, allowing us to see if JeL evoked a desire to connect further with nature. In Figure 9, we can see that while the number of participants choosing the generic retail store card was similar between the two installations, participants of JeL chose nature-related prizes far more than the participants of the other installation.

Breathing Data

We recorded breathing sensor data during the festival from the 63 participants who interacted with JeL. We adjusted the growth responsiveness half-way through the night to make it easier for participants to complete a fully grown coral. As such, here we focus on the last 1.5 hours of the exhibition for consistency. We have excluded any trials shorter than 1 minute, as this was insufficient to observe trends in the data. We have also visually examined data and excluded trials where it appeared that the sensor was not capturing breathing because of poor fit (shown by non-periodic signals). In Figure 10, we present representative plots of 11 trials of interaction that were at least 1 min long, showing the correlation coefficient between the pairs along with the average of those 11 trials. From Figure 10, we can see that in general there is a trend towards increasing synchronization as the interaction progresses; however, there is considerable variance in each pairs' journey towards synchronization and how long it took to achieve. In some cases, synchronization was never achieved, while in others it was gained and then lost later on and vice versa. Figure 11 shows two plots of exemplary breathing data along with the resulting correlation coefficient. The first pair in Figure 11 is an example of a positive interaction where the switch to synchronization appears as a distinct event rather than a gradual transition. The second pair is much more variable and began to synchronize, struggled for a while and then towards the end succeeded at progressively synchronizing again.

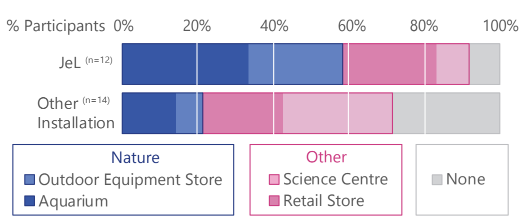

Figure 9. Participants responses to the choice of draw prize.

DISCUSSION AND DESIGN REFLECTION

The first exhibition of JeL showed that the experience of breathing synchronization was intriguing, refreshing and relaxing. It presented a novel and mesmerizing interaction that captures participants' curiosity. Our data points in the direction of new research questions about the potential of breath-responsive systems for fostering connections, the qualities of

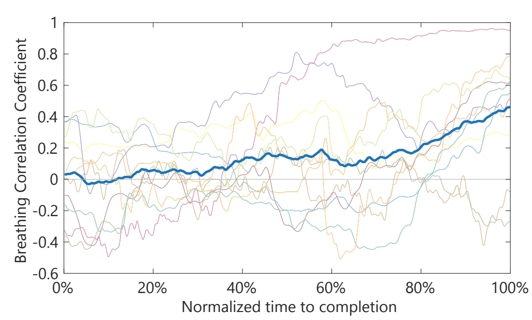

Figure 10. 20 second window correlation coefficients between 11 pairs of participants over duration of interaction (% of time to completion). Each line represents one pair while the dark blue line is the average.

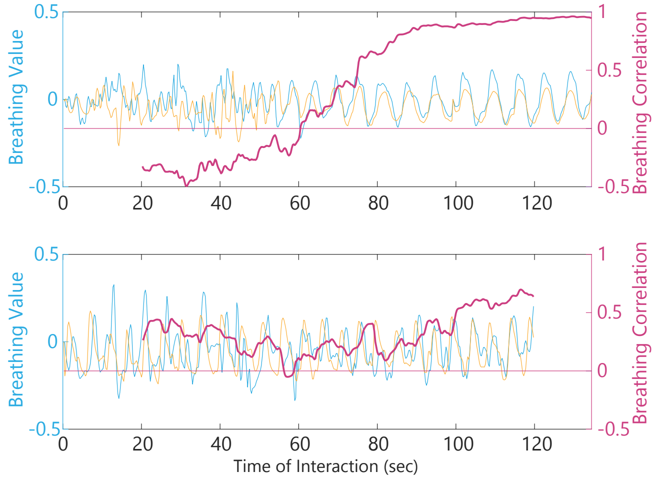

Figure 11. Plots of two exemplary interactions. The left y-axis and blue and yellow graphs show the raw breathing value while the right y-axis and magenta line show the resulting correlation.

the emerging experience and elements that could have an effect on it. While there is a considerable opportunity to refine the system and extend our investigation to determine whether the preliminary observations of our evaluation are generalizable, we leave this for future work and focus instead on the takeaways we discovered as designers of the system. Here, we reflect on our process and design decisions that lead to successes of JeL.

Biofeedback Mapping Though Reverse-Synchronization: From our observations, the most successful aspect of JeL was the mapping of the jellyfish swim animation to breathing. It was intuitive and mesmerizing to users, particularly in conjunction with the audio feedback that made the subjective experience of increasing synchronization more profound. While there are theories applicable to mapping breathing, such as metaphoric (e.g. more is up) and isomorphic mappings (e.g. lung expansion=jellyfish expansion) [48], these theories are not sufficient for more complex mappings that affect more than a single parameter (e.g. swim animation). Our design process followed an iterative approach where we experimented with different mappings through "reverse-synchronization." Here, we relaxed and observed our experience while watching or listening to cyclic aspects of our prototype. By experimenting with different parameters without any breathing input we were able to observe the natural synchronization of our breathing with the audio-visual stimuli. Attending to this tacit alignment informed us of what mapping would be most intuitive.

Implicit Priming and Set and Setting: While the main goal of JeL is to support the feeling of connection, we observed that it can only be enabled if participants are relaxed. In fact, participants were observed to synchronize better when they simply relaxed than when they actively pursued synchronization. Thus, as a mediating goal, JeL had to first elicit relaxation, which created the environment for synchronization to develop naturally and from where connection could emerge. The breathing interaction, mesmerizing jellyfish and the immersive soundscape supported this mediating goal. This aligns with other breath-responsive systems for relaxation [100].

At times, the explicit goal of synchronizing and growing a coral inhibited a positive experience if participants perceived synchronization as a challenge to accomplish. While movement syncnhrony studies have shown that an explicit goal of synchronization can facilitate the process and its outcomes [72, 75], in JeL, we observed that the explicit goal may have been counter-productive. The best strategy for synchronizing seemed to be for participants to relax instead of *trying* to match each other's breathing. Attempts to match breathing seemed to lead to a 'chase' where both participants saw the other as the leader and tried to match their breath, resulting in a self-perpetuating misalignment. The NMSPI results align with this observation as it indicated that both participants felt they were following their partner rather than leading them. The *Exhale* [81] installation demonstrated that simply sharing breathing information could lead to synchronization without explicitly stating this as a goal. Supporting a state in which connection could occur thus became the primary goal, and the emphasis on synchronization was reduced, to foster a setting that can encourage more natural synchronization. To allow for a more natural connection, we later avoided priming participants with the goal to synchronize and connect, instead simply instructing them to "relax and explore the interaction through their breathing." Thus we found the best way to prime them for synchronization, was not to prime them at all.

Unhurried Interaction: While participants were able to become immersed in JeL in spite of the hurried surroundings of the festival, a slower paced interaction in a calmer environment would have enabled more opportunities for connection. The tightly constrained 5-minute participation window led to hurried interactions where more time was used up putting on the sensors than actually engaging in the experience. An interaction that matches immersants' own pace would thus lead to a better experience. Regardless, the slowness of the interaction provided a refreshing break from the fast pace of other installations. Similarly, this type of slow-paced experience could provide a relaxing break from the blistering technologically mediated experiences that we are accustomed to.

Most participants found the experience of JeL to be relaxing and meditative. While the focus of JeL was on fostering the feeling of connection between participants, before this can be enabled, immersants have to connect with their own breathing akin to other mindfulness focused applications [68, 80]. Biofeedback-based mindfulness applications have frequently been criticized for the use of visual feedback that takes attention outwards [58]. As visual feedback can be distracting and misdirect attention, it is important to design those visuals to support immersant's attention to their own intrapersonal and interpersonal processes so that they can use the system to sensitize their attention and learn to recognize, control and experience these processes beyond the extents of the system.

Supporting Existing Relationships: The pre-existing relationship between participants seemed to significantly affect their experience in JeL. Participants who were already in a close relationship reported a stronger effect on their relationship more frequently than participants who did not know each other. Thus, JeL seemed to provide the most meaningful interaction for people who are already connected through some established relationship. Further research questions arise from this about how our relationships shape our mediated interactions. While the observable experience of JeL is the same, the meaning of the interaction and the user experience that arise from it are significantly affected by the existing relationship. On a technical level, the experience of JeL is comparable to breath-pacing systems such as *Meditation Chamber* [86], but the social aspect greatly transforms the experience.

Immersion Through Sound and Sensory Substitution: Undoubtedly, the choice of HMD- vs. projection-based interaction has an effect on the user experience and immersion [15]. While participants using the HMD tended to be less aware of their surroundings, projection-based interaction still provided an immersive experience. Substituting the loudness of the exhibition space with the sounds of waves crashing overhead created an immersive space drastically different from its surroundings. The haunting sound of the distant whale call as participants synchronized was particularly compelling and formed a critical component to the experience.

Lasting Experience Through Communal Creation: The contribution towards building a coral reef created a gratifying reward for participants who saw their contribution to something larger that spanned the duration of the event. This allowed participant to leave a virtual record of their interaction expanding their connection to others through time, similar to *Where Thoughts Go* [77]. This prolonged the experience beyond the 2 minute interaction, as participants can come back to the installation and see their creation throughout the night, reminiscing about their experience and expanding their connection to the whole community of the exhibition visitors.

Positive Experiences for a Positive Message: Many environmental installations focus on the negative effects of humanity (e.g., *Unexpected Growth* [96]). Instead of raising awareness and imposing concern and guilt, in JeL, we wanted to instead create a positive affective connection to nature that could encourage people to collaborate in caring for the environment. Connecting through breath with underwater creatures and as a community growing a coral reef together resonated with participants, giving them a pleasant experience, but also stimulating them to think about nature. Some indication of this effect could be observed in participants draw prize selection, which indicated that they sought more experiences with nature. This observation motivates an interesting research question about the potential of breathing synchronization to create connections with creatures we normally wouldn't feel connected to such as jellyfish and corals. While many breath-based systems use nature-based imagery [69], there has not yet been much discussion and investigation of its potential to support connection not only between humans but also with the environment.

User Experience of the Sensor: The least successful aspect of the current iteration of JeL was the breathing sensor that was very sensitive to variations in fitment and participant physiology. The sensor itself is an important factor in user experience which is rarely discussed in the context of bio-responsive systems. As the sensor is placed around participants' diaphragm it can incidentally highlight the differences between participants' physiques. This could even be a source of reduced accessibility, making some participants feeling 'unfit' for this experience. We had to wrap the sensor around some participants twice to barely reach the right tightness, while for others the sensor had to be loosened and significantly stretched. This technical aspects that happen in the preparation of the experience could notably effect the state in which participants start their interaction. Thus, the choice of the breathing sensor is not only a pragmatic decision, but also significantly influences the user experience it provides for diverse audience.

Challenges and Limitations:

While we had anticipated synchronization would develop gradually, it seemed to be a more instantaneous switch from asynchronous to synchronous breathing. As such, the mapping of synchronization to coral growth could be improved to provide more immediate feedback. As breathing parameters are calculated through an FFT, the synchronization score reflects the past 16 seconds of the interaction, which resulted in participants feeling like the system was not very responsive. To address this, we will adopt a faster method of evaluating synchrony in real-time such as a fast wavelet transform [49].

Our results should be interpreted with caution, since the evaluation was conducted 'in-the-wild', and has several limitations: small sample size, diverse relationships between participants, preferences for projection over HMD, limited ability to collect validated psychometrics, our focus on visitor's experience over study. However, it has the benefit of having greater ecological validity by being more true to how such installation would be actually experienced.

CONCLUSION

JeL was an overall success in its first public exhibition. Despite some problems, users nonetheless indicated that it was a compelling experience. While there were a variety of paths towards synchronization, most users were able to synchronize their breathing with each other and grow a coral structure. Our main contribution is the system itself along with our reflections of what led to its successes and failures. Through this, we demonstrate the feasibility of encouraging breathing synchronization through an aesthetic experience, not shown before. The limitations encountered can help guide further research into immersive platforms for synchronization. While the evaluation of the system is limited by the number of participants, and we can not perform any quantitative analysis or make any generalizable claims – the results do nonetheless point to research directions which could be fruitful.

JeL is a promising first step towards using VR to create intercorporeal interactions through physiological synchronization fostering the feeling of connection. There could be many ways to support intercorporeal connections with technology, and there is much more to explore in this emerging design space. Through this research, we will understand how the mediated practice of breathing together can become a tool for building stronger connections with others and nature.

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