Cultivate: Respiratory Biofeedback for Meditation in Virtual Reality

ROXANNE DUCHESNE, University of Calgary, Canada
EHUD SHARLIN, University of Calgary, Canada

Fig. 1. Meditation environments from our VR application: *Cultivate*. Left: *Windy Falls*. Right: *Sonic Dunes*

While breathing meditation is a proven way to reduce stress and anxiety, many people struggle to find the motivation to perform breathing meditations regularly. Our prototype application, named *Cultivate*, physically senses a user's breathing and translates their breath into visual and audio biofeedback in a virtual reality (VR) environment; making breathing meditation more engaging, enjoyable, and relaxing. *Cultivate* implements a proven breathing technique called heart rate variability (HRV) biofeedback training to help individuals to breathe slower and more consistently. In our prototype application, we combine HRV biofeedback training with meditative VR environments that visualize a person's breathing. By having users hold a VR controller to their stomachs, *Cultivate* can monitor their breathing and tangibly connect them to the feeling of their breath. Throughout the development of our application, we identified several design strategies for how to use visual and auditory biofeedback to enhance relaxation. Our proposed design strategies are: ensuring biofeedback visualizations are subtle, including points of focus, creating an open, cohesive, and predictable VR environment, and utilizing physical sensations. These strategies may be utilized in future VR applications to create responsive meditative environments that physically connect a user to their breath to enhance well-being.

CCS Concepts: • **Human-centered computing** → **Interaction techniques**; **Virtual reality**.

Additional Key Words and Phrases: Respiratory Biofeedback, Meditation, Heart Rate Variability

1 INTRODUCTION

Our prototype application, named *Cultivate*, uses the immersive capabilities of virtual reality (VR) to create engaging breathing meditations to help individuals reduce stress and enhance relaxation in their daily lives. As the world has shifted more online, VR presents an opportunity for people to enjoy relaxing virtual environments throughout the day from their home or office [9]. We named our application *Cultivate* as its primary use is to help people cultivate their ability to breathe at a relaxed pace, even when not using the application. Within *Cultivate* the meditations teach

Manuscript submitted to ACM

a breathing technique called heart rate variability (HRV) biofeedback. We chose this breathing technique because it has been proven to reduce stress and anxiety [4], among other benefits such as increased athletic and cognitive performance [6][7]. HRV biofeedback training aims to maximize a person's HRV by teaching them to breathe at their resonance frequency, which varies per person and is typically in the range of 4-6.5 breaths per minute [11]. While HRV biofeedback training began by simply showing numerical indicators and charts of a person's breathing, this approach made receiving negative feedback frustrating [8]. To mitigate this frustration a variety of more enjoyable and engaging biofeedback visualizations were developed [10] [13]. We chose to use VR to enhance HRV biofeedback training because VR's immersive nature makes it a promising tool for therapeutic benefit [5]. To track the user's breathing *Cultivate* requires the user to hold a VR controller to their stomach [2]. We found that this action helps people tangibly connect to their breathing by feeling the movement of their stomach as they breathe. Through surveying the existing non-VR HRV biofeedback design space we have discovered techniques for how HRV biofeedback training applications can be implemented. Through implementing different techniques in *Cultivate* we were able to create design strategies for how to best implement VR biofeedback breathing meditations.

2 RELATED RESEARCH

2.1 Heart Rate Variability Biofeedback Based on Slow-Paced Breathing With Immersive Virtual Reality Nature Scenery

Blum et al. (2019) found that slow-paced breathing in a VR environment with nature scenery produced a positive effect on participants' HRV values [1]. The study found that slow-paced breathing in VR had a comparable effect on HRV values to traditional slow-paced breathing [1]. Additionally, the study found that the VR implementation; "buffered perceived stress in the subsequent stressor task, increased relaxation self-efficacy more, reduced mind wandering, helped participants focus on the present moment, and helped preserve attentional resources" [1]. While Blum et al.'s (2019) study placed participants in VR environments, their respiratory biofeedback was only delivered through audio. In contrast, our research is focused on using visual and auditory biofeedback within VR.

2.2 Development and Pilot Test of a Virtual Reality Respiratory Biofeedback Approach

Blum et al. (2020) conducted a pilot study with 72 participants to determine if a VR controller could be used successfully as a breath tracking device [2]. The application Blum et al. (2020) developed uses the positional tracking on the VR controller to measure the user's breath by placing the controller on the user's abdomen as they breathe [2]. The study found that the VR controller could provide a satisfactory user experience while being low cost and unobtrusive [2]. Our application, *Cultivate*, implements a modified version of Blum et al.'s (2020) algorithm to detect breathing rate.

3 DESIGN & IMPLEMENTATION: *CULTIVATE*

Cultivate uses a modified version of the algorithm developed by Blum et al. (2020) to track the user's breathing [2]. This tracking is accomplished by the user holding the controller to their abdomen while they breathe [2]. The movement of the user's abdomen is then tracked and moving averages are used to determine the user's breathing rate [2]. We have found that when users hold a VR controller against their stomachs they can feel and further connect to their breathing, adding to the meditative experience. Our application currently has two breathing meditations, *Sonic Dunes* and *Windy Falls*.

3.1 *Windy Falls*

This meditation takes place in a river valley (Figure 1). When the user breathes in the wind blows towards the user and when the user breathes out wind blows away from the user. Additionally, the sky changes color when the user breathes in and out. Seeing these subtle visualizations of their breathing gives users a greater awareness of their breathing and helps users relax [8]. To guide the user a soft gong sound is played every 5 seconds. The gong's audio cues inform the user when to breathe in and out to match their resonance frequency, which we set to 6 breaths per minute. We chose a river for the setting of this exercise because spending time in natural environments has been found to increase people's productivity and lower their stress levels [3].

3.2 *Sonic Dunes*

The *Sonic Dunes* desert environment features two systems that slowly turn on when the user is breathing at their resonance frequency and slowly turn off when the user is not breathing at their resonance frequency (Figure 1 and Figure 2). The first system features audio that progressively becomes more complex and vibrant when the user breathes at their resonance frequency. The second biofeedback system slowly changes the environment from night to day. When the user stops breathing at their resonance frequency both systems slowly revert. Unlike *Windy Falls*, which gives the user biofeedback for each breath, the *Sonic Dunes* environment changes gradually. We have found that this type of gradual change tends to be less obtrusive and more suitable for relaxation. Additionally, since *Sonic Dunes* does not have any elements that indicate when a user should breathe in or out to match their resonance frequency the *Sonic Dunes* environment can help users learn to intuitively feel when they are breathing at their resonance frequency. Users can then employ this knowledge to breathe at their resonance frequency whenever they need to relax throughout the day.

Fig. 2. *Sonic Dunes* environment shifting from night to day.

4 DESIGN PRINCIPLES

As we developed *Cultivate* we discovered several design strategies that help to create a meditative environment that makes receiving breathing biofeedback relaxing, immersive, and grounded in the subtle physical sensations of breathing. These design strategies are: ensuring biofeedback visualizations are subtle, including points of focus, creating an open, cohesive, and predictable VR environment, and utilizing physical sensations.

4.1 Ensuring Biofeedback Visualizations are Subtle

When biofeedback visualizations match a user's breathing 1-to-1 any inconsistencies with the breath tracking can make the visualization feel unresponsive and frustrating. Two strategies can be used to combat this problem. The first is to make any visualizations that correlate 1-to-1 with a user's breathing subtle. For example, in the *Windy Falls* environment the wind subtly changes direction depending on if the user is breathing in or out. The second strategy is to use a more progressive biofeedback delivery method, as seen in *Cultivate*'s *Sonic Dunes* meditation exercise.

4.2 Including Points of Focus

When evaluating the *Sonic Dunes* breathing exercise a major design principle we discovered is that a consistent and fascinating moving element makes an environment better at holding a user's attention. In traditional meditation, people are often told to focus on their breath [14]. This functions as a point of focus throughout the meditation and helps prolong concentration during a meditation [14]. A visual point of focus works similarly in VR as it gives the user an element to concentrate on without being overstimulating. Additionally, by having users feel the movement of their stomachs as they breathe, VR applications can utilize the traditional physical sensations of breathing as a point of focus.

4.3 Creating an Open, Cohesive, and Predictable VR Environment

A relaxing VR environment should be; open, cohesive, and predictable. The openness of an environment builds immersion by allowing the user to look in any direction and see far off into the distance without any objects obstructing their view [9]. To create a cohesive scene all visual elements should follow the same theme and tone. Additionally, the scene should be free from visual bugs that could distract the user. Finally, the environment should be predictable. Making sure that a user's expectations of an environment are consistent with what that environment delivers is important in maintaining a stress-free environment. For example, when creating a virtual environment with wildlife any animals that will appear in the environment should be visible when the user first enters the environment. This prevents the environment from animals appearing suddenly and startling the user.

4.4 Utilizing Physical Sensations

The final design strategy is utilizing physical sensations to ground a user in their breathing. Vidyarthi et al. (2012) found that a key element of relaxation is an immersion into subtle physical sensations [12]. However, VR, while visually immersive, can unintentionally tune out subtle physical sensations, like breathing. To counteract this, it is important that breathing meditations in VR intentionally connect the user back to the physical sensation of their breath. For example, in *Cultivate* users feel the movement of their stomachs as they breathe by holding the VR controller to their stomachs. Feeling this movement tunes users back into the subtle physical sensations of their bodies, including feeling their breath enter and exit their body, and fill their lungs.

5 CONCLUSION & FUTURE WORK

VR is a promising medium for making biofeedback breathing meditation more accessible and enjoyable. With people spending more time at home using immersive virtual environments can help people recharge and relax. Through creating *Cultivate* we formulated several design strategies to aid in the future development of VR applications that can help people become more physically connected to their breathing. Further research is needed to determine the effectiveness of our proposed design strategies and to expand on *Cultivate*'s design.

ACKNOWLEDGMENTS

We would like to extend our thanks to the uTouch research group at the University of Calgary for being a supportive and thoughtful research community.

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