Biosensing with Virtual Reality

Lab 58 Technology Research Brief

February 2021

Combining biofeedback and biometrics with **virtual reality (VR)** has been explored for over a decade, but with the recent increase in accessibility of consumer VR headsets, a burgeoning field has begun to materialize. Evidence shows that using biofeedback to dynamically alter a VR experience can increase its effectiveness.[1] Eye-tracking technology with VR could lead to more powerful **head-mounted displays (HMDs)**, as well as enhance user interactivity, comfort, and security.[2] Biosensing in VR has attracted attention for therapeutic uses and gaming but can also enhance the use of VR for simulations and training.

KEY TAKEAWAYS

Using VR with biofeedback can increase its effectiveness, leading to better VR hardware and experiences.

Biosensing and VR are commonly used for therapeutic interventions and health care.

The VR and biometrics markets are projected to grow exponentially over the next 5–7 years.

Defining Biosensing, Biofeedback, and Biometrics

Biosensing is an umbrella term that encompasses biofeedback and biometrics and refers to technology that can capture biological data. **Biofeedback** describes electronic monitoring of a normally automatic bodily function and is used to train someone to acquire voluntary control of that function. Biofeedback is typically used with anxiety management and other interventions but can be extended to uses such as heart monitoring during physical activity. **Biometric recognition**, or simply **biometrics**, is the automatic recognition of individuals based on their biological and behavioral characteristics.[3] Common uses of biometrics include fingerprint recognition, face recognition, iris scanning, gaze detection, and DNA matching.

Biosensing as a Product

Together, biometrics and biofeedback are already an integral part of daily life. The average smartphone can unlock with a fingerprint or facial scan; DNA genealogy tests are readily available for purchase; smartwatches, fitness trackers, and other wearables are pervasive and only growing in popularity; and off-the-shelf eye tracking can be bought for home usage. One estimate states that by 2025, the biometrics market will grow to $77 billion.[4]

Photo by Jessica Lewis, Unsplash

[1] Costa d Souza, et al. (2018). "The Effects of Physiologically-Adaptive Virtual Environment on User's Sense of Presence." 20th Symposium on Virtual and Augmented Reality.

[2] Rogers, S. (2018). "Seven Reasons Why Eye-tracking Will Fundamentally Change VR" Forbes.

[3] Biometrics Institute. Retrieved from biometricsinstitute.org/what-is-biometrics/

[4] Uță, I.-C. (2020). Global biometrics market expected to grow to $76 billion by 2027.

VR Hardware

The VR headsets listed below are all commercially available (or will be in the near future) and feature biosensing through the integration of eye tracking. Other wearable devices can be used in tandem to add other types of biosensing.

HP Reverb G2 Omnicept Edition

The HP Reverb G2 captures gaze and pupil size in real time. This feature enables higher visual fidelity wherever the user is looking and reduces image quality in the periphery. HP and Tobii (makers of eye tracking hardware and software) claim this results in performance gains. Unlike other options, this headset also captures heart rate and facial muscle movement.

In a win for ease of use, the Reverb G2 utilizes inside-out tracking; no base stations are needed to use the headset. This headset, and the version without biosensing, should be looked at as strong "default" options for VR on computers.

Vive Pro Eye

Released in 2019, the Vive Pro Eye is only available as an enterprise product. This HMD is the existing Vive Pro with Tobii eye tracking built in. This means that eye tracking is the only update to the hardware—and unlike the other examples, it still requires base stations for tracking hand movements. Although expensive at $1,000, it is an excellent VR solution with a proven track record. But ultimately, it is difficult to recommend the Vive Pro Eye over the upcoming Reverb G2.

Pico Neo 2 Eye

The Pico Neo 2 Eye is an enterprise-focused standalone HMD; users do not need to plug the headset into a PC. The main drawback is that the HMD requires apps to be streamed from a PC or using Pico Digital Platform (this affects final commercial delivery only). For use cases that cannot have users tethered to a computer, this HMD is ideal.

Research Projects

Biofeedback and VR offer a wealth of possibilities to research, with many examining interventions for mental and physical health; however, implementing biofeedback with VR is not a one-size-fits-all solution, and the cost of integrating the technologies must be considered with potential effectiveness and VR app/game/simulation designs.

The Intrepid Project

Integrating biofeedback technologies with VR is not a new development. The Intrepid Project, developed to reduce anxiety in users by introducing mindfulness techniques, dates back to 2009.[5] This project was set on a virtual tropical island where patients' physiological parameters affected the intensity of waves, a campfire, clouds, and a waterfall as the patients calmed down following a therapist-induced stressor (Figure 1). Physiological data were captured via galvanic skin response, heart rate (HR), respiratory rate, body temperature, and muscle tension.

Figure 1:

A series of screenshots from The Intrepid Project depicting how the intensity of the clouds change based on a patient's physiological state.

DEEP

DEEP helps children who are at risk for anxiety and utilizes players' diaphragm expansions (measured with a variable resistor/stretch sensor) in conjunction with a VR game set in an underwater fantasy world.[6] Players in-game are informed of their state of breathing by a circle that expands and contracts, and resistance on the sensor is decreased as players inhale correctly (Figure 2). A pilot study suggests that DEEP and similar projects could provide an effective intervention for anxiety, and further research shows potential as an intervention for disruptive classroom behavior.[6,7]

Figure 2: Screenshot from DEEP depicting the environment and breathing circle

[5] Repetto, C., et al. (2009). "The use of biofeedback in clinical virtual reality: The intrepid project." Studies in health technology and informatics, 144, 128-32.

[6] Van Rooij, et al. (2016). "DEEP: A Biofeedback Virtual Reality Game for Children At-risk for Anxiety." CHI Conference Extended Abstracts, 1989-1997.

[7] Bossenbroek R, W. A.-A. (2020). "Efficacy of a Virtual Reality Biofeedback Game (DEEP) to Reduce Anxiety and Disruptive Classroom Behavior: Single-Case Study." JMIR Ment Health , 7(3).

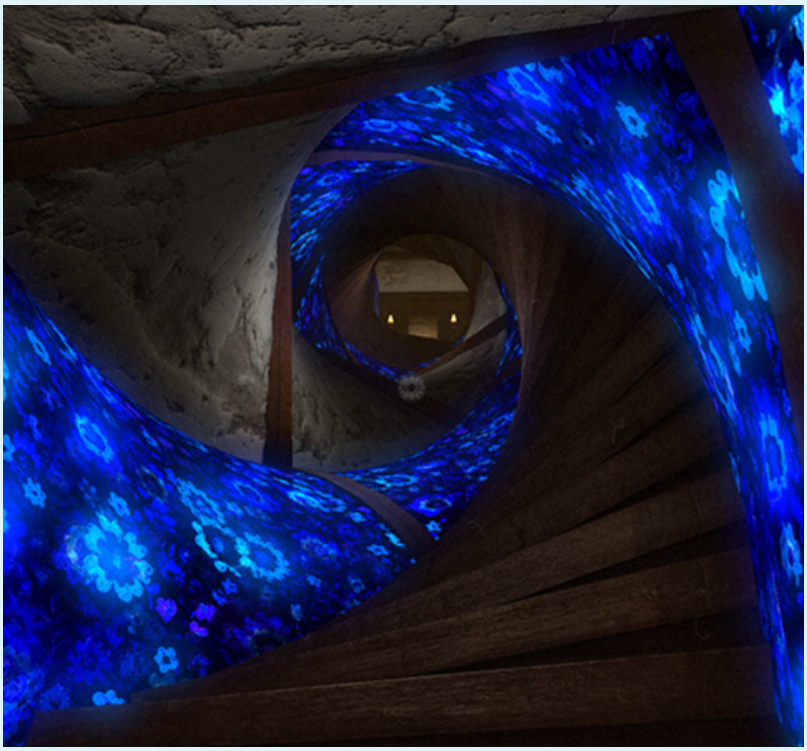
Nevermind

Described as a biofeedback-enhanced adventure thriller game, Nevermind reacts to fear and stress using run-of-the-mill technology—such as a webcam or heart rate sensors—to fluctuate the game's difficulty and the stressors presented.[8,9] Users explore the subconscious of (fictional) trauma victims and attempt to treat them as they discover repressed memories in each patient's inner psyche.

The game is designed around an astonishing amount of physiological and psychological inputs, all of which are optional; these inputs include capturing user emotions via webcam and Affectiva's Affdex technology, sensing heart rate from a wide array of supported wearables, and tracking eye movement via Tobii Eye Tracker. Additionally, the game supports Intel RealSense Technology for exclusive game content, gesture controls, and biofeedback without having to wear a sensor. The game can alter the gameplay with as little as one biosensing input. When combining emotional and physiological input, Nevermind identifies if increased user arousal is negative (e.g., fear or stress) or positive (e.g., excitement or joy). This is a crucial element for a game that can help combat anxiety and other mental health issues.[9]

HMD use increases the immersion and intensity of Nevermind but does not alter gameplay functionality. The VR version has one main drawback—eye tracking and emotion tracking are incompatible. That said, heart rate sensing does enhance the VR experience.[9] With some current and future HMDs incorporating eye tracking, future games or applications could take advantage of physiological and emotional inputs.

One primary challenge during Nevermind's development involved collaboration. Several companies did not want to be associated with a game, and even if a software development kit or an application programming interface is readily available, the game supports partnered device makers only.[9] For researchers at RTI International, it is vital to be aware of challenges that may come from developing with wearable technologies. Equally as important are the considerations for seeking out partners and/or collaborators.



A twisting staircase in the surreal virtual world of Nevermind

Photo by Flying Mollusk, LLC.

Additional Research Projects

Implementing heart rate variability (HRV) biofeedback and VR can also have benefits for reducing stressors and learning mindfulness. Researchers from the University of Freiburg had participants wear a Polar H9 chest strap for measuring heart rate, and one group also wore an HMD to experience a virtual beach at sunset. Their findings suggest that utilizing VR with HRV increased relaxation and self-efficacy. Additionally, it reduced mind wandering, increased focus on the present moment, and "conserved attentional resources" when compared to viewing graphics on a computer monitor.[10]

For researchers aiming to discover how users could affect their own cardiac activity for anxiety intervention or other possibilities, the pairing of biofeedback and visualizations of synchronized heart patterns can yield the greatest outcomes. Research shows that synchronizing a user's biorhythms in real time is the most appealing representation.[11]

Finally, utilizing biofeedback and VR in tandem has been shown to benefit stroke rehabilitation via electroencephalogram and electromyography measurements.[12] This finding demonstrates the effectiveness of biosensing and VR.

[8] Flying Mollusk, LLC. (n.d.). Nevermind the Game. (Flying Mollusk, LLC)

[9] Reynolds, E. (2020, 12 4). Interview about Nevermind and biometrics.

[10] Blum Johannes, R. C. (2019). "Heart Rate Variability Biofeedback Based on Slow-Paced Breathing With Immersive Virtual Reality Nature Scenery." Frontiers in Psychology, 10.

[11] S. Gradl, M. W. (2018). "Visualization of heart activity in virtual reality: A biofeedback application using wearable sensors." 2018 IEEE 15th International Conference on Wearable and Implantable Body Sensor Networks (BSN), (pp. 152-155). Las Vegas.

[12] Marin-Pardo O., V. A. (2019). "Electromyography as a Suitable Input for Virtual Reality-Based Biofeedback in Stroke Rehabilitation." In C. Stephanidis (Ed.), Communications in Computer and Information Science (Vol. 1032, pp. 274-281). Orlando, FL: Springer, Cham.

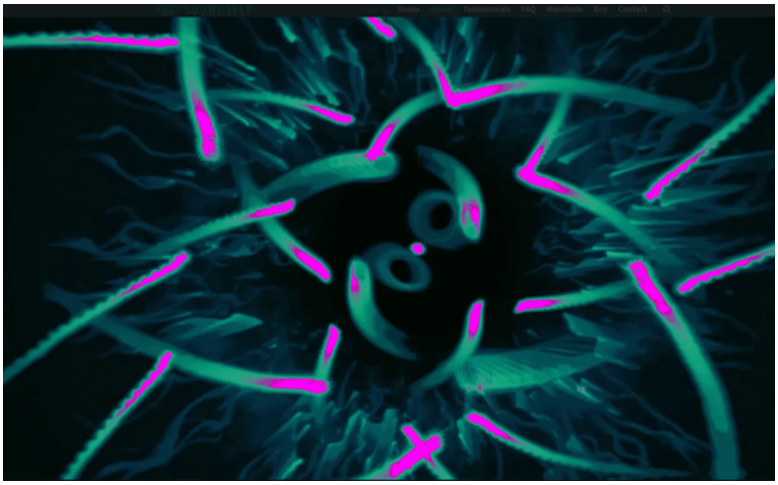
Commercially Available Products

Despite researchers' enthusiasm, very few biosensing VR products are commercially available—and most are healthcare related. Nevermind is readily available for purchase, but other applications—such as DEEP—fall in a gray area where they are obtainable via an invite-only program.

Regardless of the challenge with developing and releasing a biosensing VR app, this is a nascent field that will only continue to grow as the technology becomes more affordable, smaller, and more easily available. Researchers would do well to consider mobile VR as wearables are designed primarily for mobile devices. However, mobile VR has largely been supplanted by standalone HMDs.

SoundSelf

Using any conventional microphone, a computer, and an HMD, SoundSelf guides users into a meditative state through breathing exercises and even chanting. Visually, the app is a surreal dreamscape that harkens back to the heyday of Windows Media Player—with graphics that adapt to the user's breathing and vocal inputs that are captured via the microphone.[13] Through this, SoundSelf is able to make users aware of their breathing rate. Although simple, SoundSelf is an excellent example of biofeedback and VR that does not require additional hardware. Moreover, it illustrates the benefits of short, directed experiences and out-of-the-box thinking and design.



An example of the biofeedback visualization in SoundSelf

Photo by Andromeda Entertainment

Unyte

Unyte's Journeys app sets itself apart from other meditative VR experiences with the Unyte iom2 sensor that attaches to the user's earlobe. The app (1) monitors heart and breathing rates while teaching breathing and mindfulness techniques that influence heart rate variability and (2) immerses users in several calming 3D environments. Throughout the experience, the user interface shows a breathing indicator that guides users to an optimal breathing rate.[14]

An example of the calming environments in Unyte Journeys

Photo by Unyte Health Inc., Kickstarter

Biosensing Devices

Biosensing devices come in many varieties and are made by many manufacturers. Following are some of the available products:

Smartwatches and Wristbands	Chest Straps	Cameras with Facial Emotion Recognition	Other Devices
- Garmin Forerunner	- Polar H7 and H9	- Creative BlasterX Senz3D	- Mionix Naos QG Mouse
- Apple Watch	- Garmin HR Chest Strap	- Razer Stargazer	- Tobii Eye Tracker
- Fitbit Wearables			- Unyte iom2

[13] SoundSelf. (n.d.). (Andromeda Entertainment)

[14] Kyselova, V. (n.d.). "How Virtual Reality and Biofeedback Can Improve Meditation Experience." (Jasoren)

Future Applications

There are clear therapy and healthcare use cases for biosensing in VR, but future uses could explore how the technology can be utilized outside those fields. The following sections highlight the possibilities.

Training Simulations for Firefighters

Set in a first-person view, users enter a series of environments that are based in real-world scenarios and perform tasks that are true to life, within the limitations of VR. The simulation monitors user heart and breathing rates via wearables. Additionally, it modulates the speed with which the user's virtual oxygen tank is drained as their physiological activity increases with goals that become more challenging. If multiple users from one team are in the simulation at once, then everyone's heart and breathing rates are displayed to users so they can keep tabs on the team's safety.

Surgery Simulations

The user is a surgeon in a virtual operating room. A computer avatar represents the surgeon's hand motions. The surgeon's physiological and emotional inputs are represented in relation to their influence on the surgeon's hand stability as the surgeon uses various surgical tools. If the user is stressed or nervous, then their virtual hand becomes unstable. The simulation guides users through a series of surgical procedures of increasing complexity.

Virtual Classrooms

Virtual classrooms in VR give students (and teachers) a sense of presence and normalcy compared to other virtual methods. Students gather in the virtual classroom set up by their teachers, and each person has an avatar. Everyone is able to communicate via microphone, and students can interact with their classmates' avatars during class. The virtual classroom could also incorporate other physiological and psychological inputs to monitor stress levels of students as they engage with their classmates.

Fitness Courses

Individuals use HMDs to join varying VR exercise classes of their choosing and work out in tandem with a virtual instructor. In addition, users pair their biosensing wearables so the game can modulate the intensity of workouts based on users' physiological input.

Discussion

It is important to note that many app-based psychological interventions are clinically unproven and potentially ineffective. This could unfortunately result in over-reliance and self-diagnosis.[15] Further, VR interventions can be just as effective without biofeedback.[16] Researchers should seek out health practitioners to advise them while developing and testing biosensing VR applications.[17]

Examples shown in this brief, even those specifically targeting mental health, should be investigated as a guide for experimentation with new technologies in a nascent field. The proliferation of health-oriented projects should further spur researchers into (1) exploring how biofeedback can be integrated with VR in ways that have not yet been discovered and (2) see how a truly clinically verified app could work.

Biosensing and VR is an exciting combination of technologies, which will only continue to grow as the technologies proliferate and reduce in cost. The possibilities are undefined, providing opportunities for RTI to incorporate this technology into research projects as well as commercialize this technology into products and solutions for our clients.

Learn More About Lab 58

Thanks for your interest in our work! We invite you to reach out to us for a helping hand as you explore opportunities to work with biosensing in VR.

Please reach out by emailing us at Lab58@rti.org. We will set up a 30-minute, one-on-one chat to discuss opportunities and answer any questions. We are interested in helping you find a solution that meets your needs.

For more information, contact

Lab58@rti.org

[15] Kyselova, V. (n.d.). "How Virtual Reality and Biofeedback Can Improve Meditation Experience." (Jasoren)

[16] Tinga, A. N. (2019). "Respiratory Biofeedback Does Not Facilitate Lowering Arousal in Meditation Through Virtual Reality." Applied Psychophysiology and Biofeedback, 44, 51-59.

[17] Simon Leigh, S. F. (2015). "App-based psychological interventions: friend or foe?" Evidence-Based Mental Health, 18, 97-99.