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https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7906990/

(1) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7379892/ The Use of Virtual Reality Alone Does Not Promote Training Performance (but Sense of Presence Does)

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12. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7906990/
13. **(2) https://apps.dtic.mil/sti/trecms/pdf/AD1203989.pdf** USING BIOMETRICS TO EVALUATE THE EFFICACY OF VIRTUAL REALITY LEARNING ENVIRONMENTS THROUGH THE DETECTION OF AWE

Personalizing VR Training: A Biometric Approach to Assessing and Enhancing Learner Presence

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ABSTRACT

This research paper discusses potential to enhance training outcomes by combining biometric data points with Virtual Reality (VR) training, enabling dynamic adjustment to scenarios based on the learner's emotional and physiological performance. The author explores the viability of this strategy and practicality of a prototype design to adjust the difficulty in real-time.

Virtual Reality (VR) training is increasingly used by industry for time savings and increased learning efficacy. An emerging obstacle, instructors are struggling to connect with learners in a VR simulation leading to narrow experiences. Linear training can be overly challenging or not sufficiently stimulating. This paper explores the likelihood of improved learning efficacy by incorporating biometric sensor integration leading to real time feedback; dynamic adjustment of the applications and dives into a prototype design for conducting the study.

Metrics will yield real-time monitoring of anxiety, stress, surprise, and confidence, through the integration of heart, conductivity and facial expressions. This method aims to overcome the limitations inherent in traditional VR training scenarios, where the lack of direct interaction between instructors and students can impede the effectiveness of the training. For the prototype proposed, the trainee biometric data is incorporated into an existing VR training module to enable historical data analysis versus developing a novel training.

ABOUT THE AUTHOR

Scott MacAdams is a lifelong tinkerer. A professional nuclear engineer and the founder of Humulo Engineering, an immersive training software company headquartered in Maryland, USA. A US Naval Academy graduate and 2014 Submarine Junior Officer of the Year for the U.S. Pacific Fleet, he designed and implemented nuclear training programs at sea. After earning a Master's in Engineering Management from Duke University, developed digital training for the United States Naval Academy.

In 2018, serving as CEO and lead designer at Humulo built novel VR training simulations for the United States Air Force and National Institute of Health. Humulo expanded in 2021 with the launch of a commercial software as a service, growing to over one hundred and fifty (150+) unique clients including dozens of fortune 500 companies encompassing manufacturing, logistics, construction and utilities. HumuloVR commercial off the shelf turn-key industrial training simulations number over twenty (20) unique training topics and are growing by 50% annually and have been subject to dozens of successful efficacy studies including third party. Scott’s mission for Humulo is to eliminate industrial accidents and fatalities through immersive experience.

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Introduction

This investigation proposes a use case and utilizes existing empirical data to evaluate the potential of adding biometric sensors within a virtual reality (VR) training framework to enhance learning sense of presence and therefore, training outcomes for industrial workers. Traditional VR training often falls short in accurately gauging a trainee's engagement level, potentially leading to training sessions that are either too demanding or insufficiently challenging. The following will outline the potential development of a dynamic VR system capable of assessing an industrial worker's technical competency in real-time and adjusting the training content accordingly. Such a system could be able to categorize trainees into different proficiency levels and offer tailored support or new challenges based on their real-time performance.

Real-time monitoring of trainees' emotional and physiological responses—including engagement, anxiety, stress, surprise, and confidence—through the integration of biometric sensors into VR hardware can largely be achieved with commercial off the shelf sensors and/or sensors many individuals already use on a daily basis. This enhancement is expected to improve the efficacy of VR training by providing continuous and precise feedback on trainees' physiological states, which are often imperceptible to instructors not in the simulation. By leveraging biometric data, the project seeks to overcome the limitations of traditional VR training environments, where a lack of direct interaction between instructors and trainees can hinder effective training.

Evaluating a VR learner’s emotional state is not a novel concept. A 2023 research paper focused on using biometrics to evaluate the effectiveness of VR training (2) explores the possibility of using biometric data to objectively assess a virtual reality learning environment’s ability to encourage positive learning outcomes. Additionally, research suggests that the greater the sense of presence, the higher the learning potential is with VR training (1). We postulate that dynamically adjusting training - making it easier for less experienced trainees and more stimulating for more experienced personnel, would increase the sense of presence leading to increased training effectiveness.

Current VR training models, either open-ended or restricted to automated scenarios, often isolate the trainee from the instructor, leading to suboptimal educational outcomes. To bridge the feedback gap one could connect VR systems with sensors that monitor heart rate, eye movement, and skin conductivity, thereby offering instructors a deeper insight into each trainee's learning process in addition to building interventions into the training application itself. The ultimate goal of this initiative is to enhance the immersive training experience by making it more personalized and connected to instructional expertise, thus driving significant improvements in learning outcomes for industrial VR training applications.

The pursuit of advanced training methodologies by entities such as the U.S. Navy highlights a commitment to leveraging cutting-edge technologies like Virtual Reality (VR) and Augmented Reality (AR) to enhance training efficacy. These technologies are recognized for their potential to create immersive and engaging training environments. However, a significant challenge is the potential disconnection between instructors and trainees, compounded by the systems' current limitations in dynamically adapting to individual competencies. This often results in training scenarios where learners may either be under-challenged or overwhelmed without effectively absorbing the instructional content.

The primary goal is to develop a VR/AR learning system that dynamically adapts to the competency levels of trainees across various industries, aiming to significantly improve learning outcomes over traditional training methods. This initiative necessitates a dual focus: creating immersive training scenarios that closely replicate actual operational conditions, and developing a responsive system that adjusts the learning experience in real time based on individual trainee performance. Achieving substantial improvements in learning gains requires these systems to be more intuitive and adaptive to individual learning needs.

To assess the potential enhancements offered by integrating biometric data into VR training, it is useful to consider previous studies conducted within similar frameworks. For instance, a 2022 study involving VR training modules for fire safety and confined spaces (3) demonstrated that trainees achieved a 10% higher comprehension and retention rate compared to those in traditional learning settings. Future research will compare these results not only to conventional training methods but also against existing VR training outcomes, utilizing established efficacy study methodologies. This comparative analysis will help validate the impact of biometric data integration, offering insights into how VR training can be optimized to meet the diverse needs of industrial workers more effectively.

Current Efficacy

Recent research highlights the effectiveness of VR in training, showing improvements in learning outcomes, speed of comprehension, and retention of knowledge. Virtual reality has been increasingly adopted in various educational and professional fields due to its immersive and interactive nature, which can lead to higher engagement and better learning results compared to traditional methods.

In a large-scale study by PwC, VR training was found to expedite the learning process, reducing the time required to achieve comparable outcomes by up to 40% compared to traditional training methods. Specifically, learners were up to 275% more confident in applying skills learned via VR, indicating not only faster learning but also a deeper understanding and greater self-efficacy (PwC, 2020).

VR's effectiveness extends to both theoretical knowledge and practical skills. In the realm of nursing education, a systematic review revealed that VR significantly improved students' theoretical knowledge, with a standardized mean difference of 0.97, suggesting a strong effect size compared to traditional teaching methods. Practical skills also benefited, though the heterogeneity among study results was less pronounced, indicating a more consistent quality of outcomes (BMC Medical Education, 2023).

The practical application of VR in training scenarios is supported by well-designed educational interventions. Training scenarios in VR are meticulously developed, leveraging task analysis to ensure that the training objectives are well-aligned with real-world needs. This thorough design process underpins the high effectiveness rates observed in VR training modules across different disciplines (Frontiers in Psychology, 2023).

The evidence points towards VR as a highly effective training tool that not only accelerates learning but also enhances comprehension and retention. It presents a significant advancement over traditional methods, making it a compelling choice for future training initiatives across various sectors. As VR technology continues to evolve, its integration into educational and professional training programs is likely to expand, further solidifying its role in effective learning and skill acquisition.

Shortfalls of Immersive Learning

Virtual reality (VR) training is celebrated for its ability to provide immersive, interactive learning experiences that significantly enhance both the speed and quality of training across various sectors. However, despite its advantages, there are notable shortfalls when compared to traditional training methods, particularly in terms of real-time instructor feedback and insights.

VR training has demonstrated a capacity to improve learning outcomes due to its immersive nature. Trainees can engage with complex scenarios and receive immediate automated feedback, which can be especially beneficial in high-risk industries or situations where real-life training would be impractical or dangerous. For example, VR allows for safe simulation of hazardous conditions in industries like mining or construction without the risks associated with actual physical training (SynergyXR, 2023).

Studies indicate that VR can lead to faster training processes and better retention rates. According to a report by PwC, VR-trained employees can be up to four times faster to train than classroom learners and feel more emotionally connected to the content they are learning, which significantly boosts retention and confidence in applying learned skills (PwC, 2020).

Despite its benefits, VR training falls short in areas where traditional training excels, particularly regarding real-time instructor feedback and personal interaction. Traditional training methods such as classroom-based instruction and on-the-job training provide a level of immediate, personal feedback from instructors that VR systems are currently unable to match. This interaction is crucial for adapting learning experiences to individual needs, addressing specific questions, and providing nuanced insights based on the instructor's observations of a trainee's performance (SynergyXR, 2023).

The lack of real-time instructor feedback in VR could lead to gaps in learning, particularly in complex cognitive tasks where nuanced decision-making and problem-solving skills are essential. Trainees might not receive the tailored coaching and corrective feedback necessary to refine their skills beyond the initial training scenarios programmed into the VR system (Strivr, 2023).

While VR training offers significant advantages in terms of engagement, speed, and safety, it does not yet fully replicate the personalized and adaptive nature of traditional instructor-led training. The absence of real-time, personalized feedback from an instructor can limit the effectiveness of training, particularly in fields where soft skills and complex decision-making are crucial. As VR technology continues to evolve, addressing these shortcomings will be essential to maximize its potential as a comprehensive training tool.

“Presence”

Presence is a multifaceted construct in VR that extends beyond just "being there" to include perceived realism—the extent to which the environment meets or exceeds user expectations based on their real-world knowledge (Frontiers, 2020). This perceived realism influences higher-order cognitive processes, making the experience feel more genuine and potentially enhancing learning outcomes. Studies have shown mixed results on how presence impacts learning:

while some suggest that increased presence through higher immersiveness can improve learning outcomes, others indicate no significant link, or even suggest that high presence might increase cognitive load to detrimental effects (Frontiers, 2020; Moreno and Mayer, 2004; Makransky et al., 2019).

Research into VR training effectiveness shows that VR can lead to higher learning outcomes when the training system successfully harnesses the benefits of immersive technology. For instance, studies have found that VR can enhance spatial awareness and specific task-related skills better than traditional methods (Rasheed et al., 2015; Ray and Deb, 2016). However, the effectiveness of VR also depends heavily on the design of the training modules and the ability of the system to maintain user presence without overwhelming them. The balance between realistic scenarios and cognitive overload is critical

A notable challenge in VR training is the lack of real-time feedback and insights from instructors, which are often readily available in traditional training environments. This lack of immediate instructor feedback can hinder the adjustment of learning strategies to suit individual needs, potentially impacting the overall effectiveness of the training. Moreover, while presence can enhance learning by making the training feel more real, it can also detract from it if users become too focused on the novelty or technical aspects of the VR system rather than the learning content itself.

While VR training offers promising advantages such as increased engagement and the safe simulation of dangerous scenarios, its effectiveness is highly dependent on the quality of the VR experience—especially the level of presence perceived by users. The research suggests a complex interplay between presence, learning outcomes, and user experience, indicating that more tailored approaches and further studies are necessary to optimize VR training systems. The field must address these challenges, particularly the need for effective instructor feedback mechanisms, to fully realize the potential of VR in training applications.

Based on these indications, it is reasonable to conclude that a virtual training environment that adapts to the user's individual emotional state would lead to higher levels of presence.

IMPACT OF BIOFEEDBACK ON ANXIETY REDUCTION IN TRAINING

One notable study, a meta-analysis, examined the impact of Heart Rate Variability (HRV) biofeedback training on stress and anxiety levels. The analysis included 24 studies with a total of 484 participants and found that HRV biofeedback significantly reduced self-reported stress and anxiety. The study highlighted that HRV biofeedback is associated with large reductions in these psychological states, demonstrating its potential as an effective tool for improving mental health and training outcomes (Cambridge Online).

Another systematic review focused on the effectiveness of mindfulness-based stress reduction (MBSR) programs in medical students. This review included randomized controlled trials that showed significant reductions in psychological distress, anxiety, and depression among participants who underwent MBSR training compared to control groups. These findings suggest that integrating mindfulness techniques into training programs can enhance overall well-being and reduce stress, thereby potentially improving learning efficacy (BioMed Central) (BioMed Central).

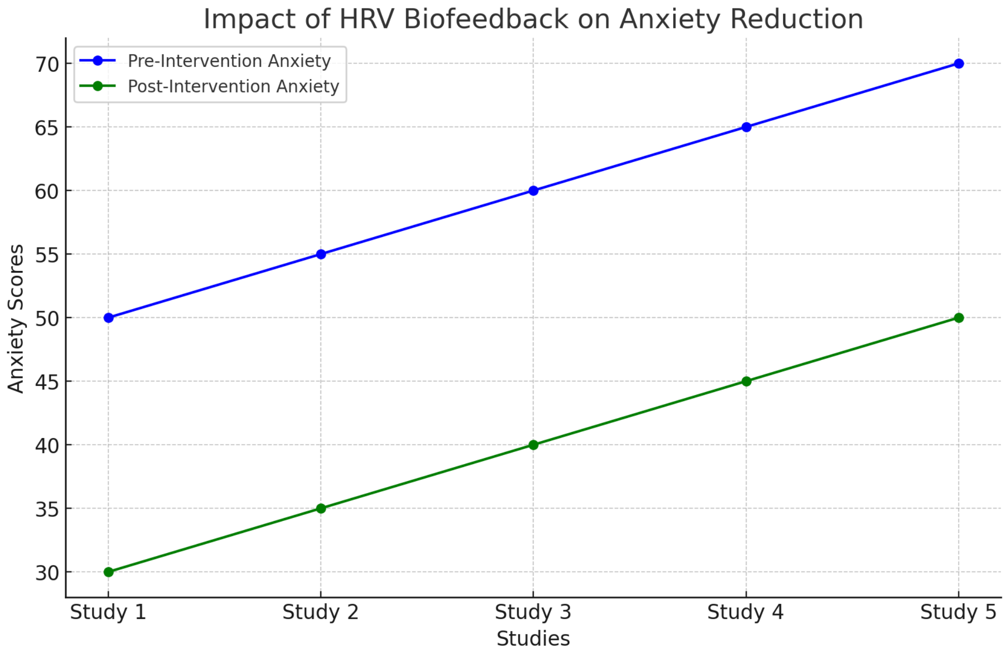

Figure 1: This graph represents the average reduction in anxiety scores before and after the intervention.

This graph shows the average anxiety scores of participants before and after undergoing HRV biofeedback training, illustrating the significant reduction in anxiety levels across multiple studies.

Biometric Sensors

Integrating biometric data into training systems can enhance the adaptability of these platforms by responding to a trainee's emotional and physiological states. The research highlighted by the NCBI (2023) discusses the use of a wearable wristband equipped with sensors capable of monitoring stress indicators such as heart rate variability and skin conductance. These metrics serve as reliable, real-time indicators of an individual's stress levels.

The capability to measure stress through commercial off-the-shelf wearables allows training systems to dynamically adjust their difficulty and feedback based on the user's anxiety levels. This ensures that the learning environment is tailored to prevent cognitive overload and frustration, thereby optimizing engagement and effectiveness.

Artificial Intelligence plays a pivotal role in processing the data from these biometric sensors, enabling the training modules to evolve and respond more accurately to the user’s needs over time. For example, in scenarios that require high precision and calm, the system could reduce complexity or introduce calming elements if increased stress is detected.

Such technology holds particular promise in disciplines where performance under stress is critical, such as in medical or military training. Here, the ability to simulate challenging conditions while adapting to the trainee’s physiological responses can significantly improve the development of crucial skills.

Key Biosignals for Health Monitoring

Over the years, several biosignals have been identified as particularly useful for tracking health-related metrics such as stress. Among these, the following are recognized for their reliability and widespread use:

Heart Rate Variability (HRV): HRV measures the variation in time between consecutive heartbeats. It is sensitive to autonomic nervous system changes and can indicate the body's response to stress.

Galvanic Skin Response (GSR): Also known as skin conductance, GSR reflects changes in sweat gland activity, which increases during stress. This response is controlled by the sympathetic nervous system and offers a direct indicator of stress levels.

Electroencephalography (EEG): EEG measures electrical activity in the brain and can reflect cognitive stress through patterns like beta wave activity.

Electromyography (EMG): EMG records electrical activity produced by skeletal muscles. It is used to assess changes in muscle activation, which can increase during stress.

Each of these biosignals provides a different perspective on the body's response to stress, offering a comprehensive view when combined. Their integration into training systems, particularly those involving high-stress simulations like VR training for medical or military applications, can enhance the effectiveness of these systems. By monitoring these signals, training programs can be dynamically adjusted to the individual's stress levels, ensuring optimal engagement and learning outcomes.

Technical Approach: Biometric Monitoring for Performance Assessment

What specifically would such a VR training system look like from a hardware and software perspective? The proposed technical approach hinges on integrating biometric monitoring within the VR training framework. This approach aligns seamlessly with the objective of creating an adaptive learning environment. It involves the following key components:

1. **Integration of Biometric Sensors**: The VR system will be equipped with readily available and integration-friendly biometric sensors (e.g. Emotibit; https://www.emotibit.com/ “Wearable sensor module for capturing high-quality emotional, physiological, and movement datacapable of monitoring physiological responses such as heart rate, eye movement, and skin conductivity.. Fully open source software). These metrics combined offer insights into the student's stress levels, engagement, and focus during the training exercises. Analysis to determine the viability of commercially available sensors versus their usefulness is required.

2. **Real-Time Data Analysis for Adaptive Learning**: The collected biometric data will be analyzed in real-time using advanced algorithms incorporated locally within the application. This analysis will enable the system to understand the student's learning curve and stress thresholds. It can then adapt the complexity of the training scenarios accordingly, ensuring the student is consistently challenged without being overwhelmed. This will likely require research to be conducted to establish baseline data and continually refinement.

3. **Feedback Mechanism for Continuous Improvement**: The system will provide immediate feedback to students based on their performance metrics. This feature is pivotal in helping students identify areas where they excel and those where they need improvement, fostering a self-directed learning environment.

4. **Instructor Oversight and Intervention**: While the system offers an automated adaptive learning experience, instructor oversight is crucial. Instructors will have access to the biometric data and performance analytics, enabling them to step in when human intervention is necessary for further guidance or support.

5. **Generalizability Across Training Modules**: The system will be designed to be flexible and scalable, capable of being applied across a range of training modules. This ensures that the investment in VR technology yields broad-based benefits across various training scenarios.

In conclusion, the approach to integrating biometric monitoring in VR training is an adaptive, effective, and immersive learning environment. By focusing on personalized learning experiences, guided by real-time physiological and performance data, observations of training, ensuring preparedness and proficiency can be analyzed for better training outcomes such as trainee satisfaction, confidence to act on the job, comprehension and retention.

THE PROTOTYPE STUDY: DEVELOP ADAPTIVE VR FIRE SAFETY TRAINING

VR Fire Safety Training:

VR Fire Safety training represents a significant advancement in occupational safety training, offering an immersive and efficient learning experience. Learners can react to a fire emergency beyond simply experiencing the process of putting a fire out with an extinguisher. This type of training is ideal for this research study as it is widely used, largely standardized and existing efficacy data sets are existing and large. The integration of biometric analysis and adaptability into this already effective program can further enhance its impact, making it an ideal test case for our research into advanced VR training capabilities. Fire Safety training is required for most industrial personnel to save lives and equipment. Any incremental improvement in Fire Safety training would enhance mission readiness and have a positive impact on training costs.

Enhanced Training Description

This enhanced VR Fire Safety training retains the core elements of the existing program but introduces biometric monitoring and adaptive learning techniques to elevate the training experience.

Key Features of the Existing Fire Safety VR Program + Biometrics Added

1. **Duration and Accessibility**: Average experience length of 8-12 minutes, ensuring efficiency in delivering vital safety information. Keeping the simulation duration under 20 minutes is important to meet time savings return on investment metrics but is also conducive to higher levels of presence.

2. **Learning Objectives:** Trainees learn to identify various fire hazards (Class A, B, C), understand employer requirements for worker safety, and practice emergency responses such as alerting services, using fire extinguishers, and extinguishing fires.

3. **Biometric Monitoring for Personalized Learning**: The program will integrate biometric sensors that the user wears as well as utilize onboard sensors in the VR headset. These sensors will monitor indicators like heart rate, eye tracking, and skin conductivity, providing real-time data on the trainee's stress levels and engagement.

4. **Adaptive Learning Environment**: Based on the biometric data, the VR experience will adapt in real-time. For instance, if a trainee shows signs of high stress or confusion when identifying fire hazards, the program can offer additional hints or slow down the pace. This ensures a tailored learning experience for each user, maximizing the efficiency and effectiveness of the training.

5. **Immersive Scenario-Based Training**: Trainees will navigate a virtual industrial environment, identifying fire hazards and responding to a fire outbreak. The program will adapt scenarios based on the trainee's performance, presenting more complex challenges as their proficiency increases.

6. **Instructor Oversight and Feedback**: Instructors will have access to the biometric data and performance metrics of each trainee. This allows for targeted feedback and intervention, bridging the gap between automated training and human instruction.

7. **Outcome Measurement and Reporting**: Post-training, the system will generate comprehensive reports detailing the trainee's performance, areas of strength, and aspects requiring further improvement. This data will be invaluable for employers in assessing the efficacy of the training and for continuous improvement of the program.

By incorporating biometric analysis and adaptability into Humulo's VR Fire Safety training, we aim to create a more personalized, engaging, and effective learning experience. Through this enhanced program, we anticipate a significant improvement in trainees' ability to respond to fire emergencies, ultimately contributing to a safer and more prepared workforce.

The Study

These objectives aim to address critical aspects of the proposed approach, from technical feasibility and user experience to market potential and compliance with standards, laying a comprehensive foundation for the research and development effort in Phase I.

1. Establish the Baseline for Current VR Training Efficacy
   - Determine the existing benchmarks of VR training effectiveness in various scenarios.
   - Research Question: What are the current success rates and limitations of existing VR training methods?
2. Identify and Integrate Suitable Biometric Sensors
   - Select appropriate biometric sensors for integration into VR headsets.
   - Research Question: Which biometric sensors are most effective for monitoring key physiological indicators during VR training?
3. Develop a Prototype VR Training System with Biometric Integration (No human subject Testing in Phase 1)
   - Create an initial prototype that combines VR training with biometric data collection.
   - Research Question: How can biometric data be effectively integrated into VR training systems to enhance learning?
4. Test the Prototype for Data Collection and Processing
   - Conduct preliminary tests to assess the prototype's data collection and algorithmic processing capabilities.
   - Research Question: How accurately and efficiently does the prototype collect and process biometric data?
5. Evaluate the Feasibility of Adaptive Learning Algorithms
   - Investigate the potential of using adaptive algorithms to modify training based on biometric feedback.
   - Research Question: Can adaptive learning algorithms effectively use biometric data to personalize and enhance VR training experiences?
6. Assess User Interface and Experience
   - Evaluate the prototype's user interface and overall user experience.
   - Research Question: Is the enhanced VR training system user-friendly and does it improve the training experience?
7. Conduct a Preliminary Market Analysis
   - Perform an initial market analysis to understand the commercial potential of the enhanced VR training system.
   - Research Question: What is the market demand for VR training systems enhanced with biometric data capabilities?
8. Determine Environmental and Ethical Compliance
   - Ensure that the system's development and use comply with environmental and ethical standards.
   - Research Question: Does the proposed system adhere to relevant environmental and ethical guidelines?

9. Develop a Scalability and Integration Plan
   - Outline a plan for scaling and integrating the system into different training environments.
   - Research Question: How can the enhanced VR training system be scaled and integrated into various training settings?

CONCLUSION

The investigation into the efficacy of virtual reality (VR) training underscores the significant role of presence—defined as the user's psychological immersion in the virtual environment—in enhancing learning outcomes. The data suggests that higher levels of presence correlate with improved retention, comprehension, and a deeper emotional connection to the material, which subsequently fosters decisiveness in practical applications.

Integrating biometric sensors into VR training systems appears to be a promising approach to enriching this sense of presence. By continuously monitoring the trainee's physiological responses, such as heart rate and galvanic skin response, the VR environment can adapt in real-time to the individual's emotional state, thus maintaining or enhancing presence throughout the training session. This adaptive feedback loop not only keeps the trainee engaged but also helps in customizing the learning process to fit their unique needs and emotional responses, potentially accelerating learning curves and enhancing training efficacy.

Furthermore, the application of biometric feedback provides trainers with invaluable insights into the trainee's experience and emotional state, empowering them to fine-tune interventions and support more effectively. For instance, if a trainee exhibits signs of stress or confusion, the system could automatically adjust the complexity of the task or provide additional instructional support.

A proposed prototype study focusing on fire safety training using this enhanced VR setup could serve as a critical test case for these hypotheses. Should this endeavor be implemented, it is anticipated that the incorporation of biometric sensors will not only validate the theoretical benefits discussed but also offer practical insights into the scalability and adaptability of such technologies in training scenarios.

Thus, the strategic incorporation of biometric sensors in VR training frameworks holds substantial promise for revolutionizing training methodologies, making them more responsive and tailored to individual learners. This approach has potential to significantly boost the effectiveness of VR training, turning it into a more powerful tool for education and professional development.

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