Biofeedback in Virtual Reality:
Assessing Immersive Industrial Safety Training

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Abstract. *This study analyses biometric data resulting from a virtual reality-based industrial safety training. The current phase of the project features an advanced VR training environment. Utilizing the Design Science Research paradigm, this research involved the design, development, and evaluation of an immersive training program. In this environment, biometric data is captured for the analysis of heart rate metrics. author's evaluations based on these data have demonstrated the effectiveness of VR training in enhancing safety measures for work at heights. author's analyses of these data have be evidence of the effectiveness of VR training in enhancing safety measures for work at heights.*

1. Introduction

Many industries operate in high-investment high-operational-risk scenarios, and work accidents cause 330,000 deaths annually [Woest 2018, International Labour Organization, 2023].

Virtual reality (VR) is increasingly being integrated into safety-critical industrial training. VR creates safe and complex learning environments that promote knowledge acquisition through active involvement. However, research on the effectiveness of VR training assessment is limited [Toyoda et al. 2022]. An opportunity to understand the trainee behaviour is to collect both self-reported data and physiological metrics. In virtual reality, factors like heart rate, skin conductance, gaze, brain activity, and muscle responses offer deeper insights into how users perceive and react to their environment. Leveraging physiological measures is crucial for evaluating and enhancing the user experience.

In this context, this research aims to analyses biometric data resulting from a virtual reality-based industrial safety training. The study highlights the relevance of utilizing immersive technologies for industrial training without the need for physical presence.

The rest of this paper is organized as follows: Section 2 describes the Materials and Methods; Section 3 examines our findings; and Section 4 presents our conclusions and further research steps.

2. Materials and Methods

This applied exploratory research adopts the Design Science Research (DSR) paradigm, which advances knowledge while concurrently addressing real-world organizational applications related to the research problem or opportunity [Gregor and Hevner 2013]. According to the DSR artifact taxonomy, this research will culminate in a design recommendations artifact [Offermann et al. 2010].

The six stages of DSR will be executed: (1) problem identification; (2) defining the solution objectives; (3) designing and developing the artifact; (4) demonstrating the developed artifact; (5) evaluating the artifact; and (6) communicating the results to the scientific community. For stages 1 and 2 of DSR, the problem was identified and research objectives were established through a state-of-the-art review. For Stage 3, Unity 2022.3.22f1 was utilized as the development engine, employing the C# programming language for editing, applying 3D models, and creating the immersive training simulation for the project. This environment offers a scenario with detailed information, on-site materials, and instructions for managing tasks related to working at heights. The Samsung 7 smartwatch will be used to collect and analyze author's heart rate data, offering insights into their stress levels, focus, attention, and relaxation responses. This data will be integrated with the PICO 4 Enterprise head-mounted display to monitor physiological responses during the training (Figure 1).

Figure 1: PICO 4 Enterprise and Samsung 7 smartwatch

Steps 4 and 5 of the DSR, which involve demonstrating the artifact and evaluating it, will be addressed in future work, and step 6 consists in this publication to communicate our findings, which are described in the following sections.

3. Preliminary Results

Following the virtual experience, experimental data were collected and subjected to analysis, focusing on heart rate metrics to evaluate responses related to stress, distraction, attention, and relaxation. An evaluation framework was subsequently developed using the Design Science Research (DSR) paradigm, and the findings were systematically organized within the Experience Development section. In the subsequent phase, the Perceptions section underscored the pivotal role of virtual reality as an instrumental tool for height safety training. Finally, the data was utilized to formulate Project Recommendations for future applications, the development of immersive training programs and extending the research to a larger group of participants.

3.1. Development of the Experience

The virtual reality experience was designed to simulate industrial training, delivering an immersive environment where users can interact with workplace safety content and obtain comprehensive information about the training. The simulation replicates an industrial environment and features a dedicated area for the practical simulation of activities involving fall hazards and work at height (Figure 2).

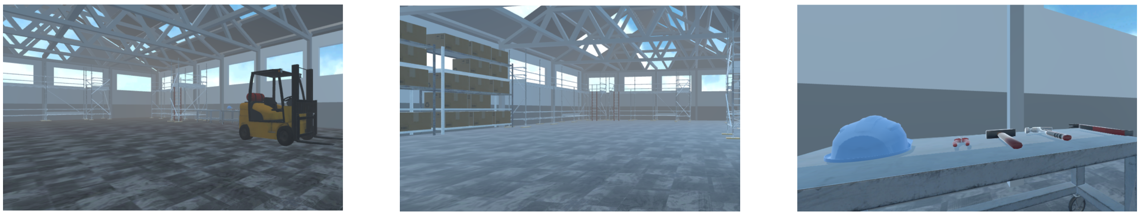

Figure 2: Images of the Developed Environment

In this immersive environment, the Samsung 7 smartwatch will collect and analyze author's heart rate data were integrated with the PICO 4 Enterprise. Furthermore, author's evaluations were collected to assess the training's effectiveness and safety.

Heart rate data were collected and analyzed to assess the author's responses to the simulation, considering different evaluation moments (T1, T2, T3, T4) across four conditions: Heart Rate, Relaxation Responses, and Stress Monitoring. The findings, including the mean, SE mean, minimum, and maximum values, are presented in Table 1.

Table 1: Descriptive Data Findings

Health Monitor	Measure	Mean	SE Mean	Minimum	Maximum
Heart rate	T1	77.5	3.536	75	80
	T2	67.5	3.536	65	70
	T3	85	7.071	80	90
	T4	92.5	10.607	85	100
Relaxation responses	T1	4.5	0,707	2	3
	T2	5	2,828	2	6
	T3	5	1,414	3	5
	T4	5	3,536	2	7
Stress Monitoring	T1	35	7.071	30	40
	T2	15	7.071	10	20
	T3	50	14.142	40	60
	T4	80	14.142	70	90

Heart Rate Analysis refers to the number of heartbeats per minute. It is a indicator of cardiovascular function and overall physiological state. An initial decrease in heart rate is observed from T1 (77.5) to T2 (67.5), followed by a progressive increase at T3 (85) and T4 (92.5). Relaxation Responses vary significantly over time, with an initial average of 2.5 at T1, a increase at T4 (4,5), and stabilization at T4 and T3 (4.0).

Stress levels, typically assessed through self-report scales or physiological markers, measure the perceived or physiological response to stressors. In this analysis, stress levels increase significantly from T1 (35) to T4 (80), with high variability observed particularly at T3 and T4. These data suggest the need for specific interventions to reduce emotional burden and improve the learning experience in VR environments.

3.2. Author's Perceptions

Author's perceptions provided feedback on the immersive experience across multiple dimensions. The virtual reality experience was deemed realistic and immersive, which contributed to higher author engagement. Heart rate data indicated stress, attention, and relaxation responses, demonstrating the experience's capability to simulate real-world working conditions at heights. Additionally, the experience was positively evaluated for its effectiveness in promoting safe practices and appropriate behaviors in high-altitude work scenarios.

3.3. Design Recommendations

Based on author's feedback and the collected data, recommendations were formulated to enhance future implementations of immersive training for height safety. The recommendations include the ongoing enhancement of simulation realism to improve training effectiveness, the establishment of a continuous assessment system to compile data across multiple training sessions for comprehensive analysis, and the expansion of training scenarios to encompass a wider range of situations and challenges that workers may encounter in real-world settings.

4. Final Considerations

This study seeks to deepen the understanding of how organizations can integrate immersive technologies to optimize training for professionals in high-risk industrial environments. Furthermore, the author's assessments of immersive experiences confirm their effectiveness, thereby broadening their applicability across various domains where users are exposed to potential hazards.

In future work, the study will expand its analysis to include additional biometric data beyond heart rate, incorporating metrics such as eye tracking, facial recognition, and body movement tracking.

5. Acknowledgements

The authors thank the SENAI CIMATEC University Centre, the Advanced Knowledge Center in Immersive Technologies (AKCIT), the Bahia State Research Support Foundation (FAPESB) and the National Council for Scientific and Technological Development; IW is a DT-1D productivity grant fellow (308783/2020-4).

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