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DOI: 13.8635/aijournals/3209836

Advancement in Human Computer Interaction and Human Physiological Modelling

ISSN: 3043-5749

Immersed and Engaged: Understanding the Physiological Response to 3D Bubble Fixations in Virtual Reality

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Abstract

Virtual reality (VR) is rapidly evolving from a gaming novelty to a powerful tool in fields ranging from therapy to training. As its applications expand, understanding how our bodies respond to VR environments becomes crucial. A recent study delved into the physiological effects of fixating on 3D bubbles within a virtual reality setting, revealing fascinating insights into the connections between visual attention, immersion, and our internal state. The study focused on exploring the correlates of physiological responses, specifically measuring heart rate variability (HRV) and electrodermal activity (EDA), while participants visually fixated on dynamically presented 3D bubbles in a VR environment. Why bubbles? Their dynamic, reflective, and semi-transparent nature makes them visually captivating and potentially evokes a sense of child-like wonder and intrigue. The result shows "Elevated Arousal" where fixations on the 3D-bubbles led to a noticeable increase in Skin conductance response (SCR), indicating heightened emotional arousal and engagement. This suggests that the visual stimulus was successfully capturing and maintaining the participant's attention.

Keywords: Virtual Reality Environment, Physiological Response, Electrodermal activity, Heart Rate, Skin temperature, 3D-Bubbles, Fixations

Accepted: 12th January, 2025
Revised: 16th February, 2025
Published: 10th March, 2025

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1 Introduction

Studies of increased engagement and increased physiological activity demonstrated a clear link between visual engagement with the 3D bubbles and heightened physiological responses. When participants were actively fixating on the bubbles, their heart rate variability and electrodermal activity showed noticeable changes. This suggests that the immersive and engaging nature of the task triggered the autonomic nervous system, which regulates involuntary functions like heart rate and sweating. ((Noton and Stark, 1971b,a; Coltekin et al., 2010)).

Heart Rate Variability as a window to cognitive load measures the variation in time intervals between heartbeats. It provides insights into the balance between the sympathetic ("fight-or-flight") and parasympathetic ("rest-and-digest") nervous systems. The study found that specific fluctuations in HRV were associated with the complexity and dynamism of the 3D bubbles. This suggests that HRV could be a valuable tool for gauging the cognitive load placed on individuals within VR environments. More complex bubble movements potentially demanded greater attentional resources, leading to the observed HRV changes.

Electrodermal Activity and Arousal (EDA), measured through skin conductance, reflects the activity of sweat glands and is closely tied to emotional arousal and cognitive effort. The study ((Michela, 2024)) revealed a correlation between peak fixation times on the bubbles and increased EDA. This reinforces the idea that prolonged visual attention to these virtual objects elicits a measurable level of physiological arousal, potentially reflecting a sense of engagement or intrigue.

These findings have significant implications for the design and application of VR experiences in designing for engagement by understanding the physiological responses to specific visual elements, developers can create more engaging and immersive VR environments. This could involve strategically incorporating elements that trigger specific physiological responses to enhance learning, elicit desired emotional states, or improve therapeutic outcomes. In the objective measurement of immersion, physiological data like HRV and EDA offer an objective way to measure immersion in VR. This is particularly useful in applications like training simulations, where it's crucial to ensure that users are fully engaged and absorbing the material. The study highlights the potential for personalized VR experiences, tailoring the environment and tasks to an individual's physiological profile. This could lead to more effective and comfortable VR therapies, training programs, and entertainment experiences. Future research would explore these relationships in more detail, investigating the impact of different bubble characteristics (e.g., color, size, movement) on physiological responses. Investigating the influence of individual differences (e.g., personality traits, prior VR experience) on these responses is also essential.

This study provides valuable insights into the interplay between visual attention, immersion, and physiological responses within virtual reality. By demonstrating the link between fixating on 3D bubbles and measurable changes in heart rate variability and electrodermal activity, the research underscores the potential of VR to elicit strong physiological reactions. As VR technology continues to advance, understanding and leveraging these responses will be crucial for creating more engaging, effective, and personalized virtual experiences across a wide range of applications. The study demonstrates that VR is more than just a visual experience; it's a full-body interaction impacting our internal physiological landscape. The proceeding section discusses more on Literature review physiological response to 3D bubble fixations in virtual reality.

2 Literature Review

Virtual Reality (VR) is rapidly evolving, offering increasingly immersive experiences. One particular application, the use of 3D bubbles as fixation targets, holds promise in various fields like visual training, cognitive rehabilitation, and even entertainment. But how do our bodies react to focusing on these virtual bubbles within the immersive VR environment? This review explores the existing literature examining the correlates of physiological responses to 3D-bubble fixations in VR, aiming to understand the link between visual focus on these elements and the resulting physiological changes ((Michela, 2024)).

3D bubbles in VR are attractive fixation targets due to their unique properties. Their inherent roundness and often-dynamic movement naturally attract attention. Furthermore, elements like color, texture, and internal reflections can be manipulated to create visually stimulating and engaging stimuli. This makes them ideal for tasks requiring sustained attention and visual tracking in a controlled environment ((Nogueira, 2015; Flautero, 2023; Stangl and Riedl, 2024)).

2.1 Eye Tracking

This provides valuable insights into gaze behavior, including fixation duration, saccade patterns, and pupil dilation. Increased fixation duration on 3D bubbles might indicate higher engagement or task difficulty. Pupil dilation, often associated with cognitive load and arousal, can reveal the mental effort required to maintain focus on the bubbles. Electrodermal Activity (EDA): Also known as skin conductance, EDA measures changes in sweat gland activity, reflecting sympathetic nervous system arousal. Increased EDA levels can indicate heightened stress, excitement, or cognitive effort associated with the VR experience and the visual task.

2.2 Key Correlates and Emerging Themes

- Task Complexity and Cognitive Load: Studies demonstrate that increasing the complexity of the task involving bubble fixation (e.g., requiring participants to identify specific bubble features or track multiple bubbles simultaneously) leads to increased pupil dilation, heart rate, and EDA, indicating higher cognitive load and effort.

- Visual Properties of Bubbles: The visual characteristics of the bubbles themselves play a significant role. Brighter colors, dynamic textures, and unpredictable movements often result in higher arousal levels and shorter fixation durations. Researchers are exploring how manipulating these properties can optimize attention and engagement.

- Individual Differences: Individual factors such as pre-existing anxiety levels, visual attention skills, and prior VR experience can significantly influence physiological responses. Individuals with higher anxiety levels might exhibit heightened EDA responses in the VR environment, while experienced

Figure 1: The Framework for scene organisation and analysis.

VR users might show lower physiological arousal due to habituation.

- Immersive Qualities of the VR Environment: The overall sense of presence and realism in the VR environment contributes to the physiological responses. Higher levels of immersion can amplify emotional responses and increase engagement with the virtual task, leading to more pronounced physiological changes.

This review reveals a growing body of research exploring the physiological impact of 3D-bubble fixations in VR. Future research needs to focus on the following:

1. Standardizing Methodologies: Developing standardized protocols for data collection and analysis will facilitate cross-study comparisons and strengthen the reliability of findings.
2. Exploring Clinical Applications: Investigating the potential of using 3D-bubble fixation tasks in VR for diagnosing and treating attention deficits, anxiety disorders, and other clinical conditions.
3. Developing Adaptive VR Systems: Utilizing real-time physiological data to adapt the VR experience to individual needs and optimize learning, training, and therapeutic outcomes. This could involve adjusting the difficulty of the task, modifying the visual properties of the bubbles, or providing personalized feedback based on the user's physiological state.

Understanding the physiological responses to 3D-bubble fixations in VR is crucial for designing effective and engaging VR applications. By further exploring the correlations discussed in this review, researchers and developers can harness the power of VR to create personalized experiences that promote learning, enhance performance, and improve well-being. The potential of this technology is vast, and future research promises to unlock even more of its capabilities in diverse fields.

3 Method

Virtual Reality (VR) is rapidly evolving beyond gaming and entertainment, finding applications in training, therapy, and research. One fascinating area of exploration is understanding how we interact with virtual environments and how those interactions affect our bodies. A recent study delving into this area investigated the physiological responses to fixating on 3D bubbles within a VR setting, offering valuable insights into the connection between visual attention and our internal state.

This study focuses on "3D-bubble fixations," essentially tracking where a participant's gaze is directed in a VR environment containing floating, interactive bubbles (Figure 1). The study meticulously monitored various physiological markers while participants explored this virtual bubble-filled world represented as their gaze points. These markers includes:

1. Heart Rate Variability (HRV): A measure of the beat-to-beat variations in heart rate, reflecting the activity of the autonomic nervous system and providing insights into stress levels and emotional regulation.
2. Skin Conductance Response (SCR): Also known as electrodermal activity, SCR measures changes

in the electrical conductivity of the skin, primarily driven by sweat gland activity, often linked to emotional arousal and attention.

3. Pupil Dilation: Changes in pupil size are influenced by cognitive workload, emotional arousal, and visual attention, offering another window into the participant's internal state.

4. Respiration Rate: Breathing patterns can be influenced by stress, relaxation, and engagement, providing a global indication of a participant's overall physiological state.

By analyzing these physiological signals in conjunction with the participant's eye-tracking data (identifying bubble fixations), the method aims to uncover correlations between where someone looks in VR and how their body responds. The purpose for applying this method includes:

1. Designing more engaging and effective VR experiences: Understanding how users respond physiologically to specific elements within VR environments can inform the design of more immersive and captivating experiences, whether for entertainment, training, or therapeutic purposes.

2. Developing personalized VR therapies: By tailoring VR environments to elicit specific physiological responses, therapists can potentially leverage VR for anxiety reduction, pain management, and other therapeutic interventions.

3. Creating realistic simulations for training: For instance, in fields like surgery or emergency response, understanding how trainees physiologically respond to stressful scenarios within VR simulations can help optimize training protocols and improve performance under pressure.

4. Gaining deeper insights into human attention and emotion: The study of VR fixations provides a unique opportunity to dissect the complex interplay between attention, visual processing, and physiological responses in a controlled and customizable environment.

4 Result

The findings of the study revealed a clear link between 3D-bubble fixations and distinct physiological changes. Specifically, the researchers observed:

1. Elevated Arousal: Fixation on the 3D-bubbles led to a noticeable increase in SCR, indicating heightened emotional arousal and engagement (Figure 2b and 2d). This suggests that the visual stimulus was successfully capturing and maintaining participant's attention.

2. Increased Mental Workload: Changes in HRV patterns suggested that focusing on the bubbles induced an increase in mental workload (Figure 3a and 3c). This could be attributed to the cognitive effort required to process the visual information, track the bubbles in 3D space, or even anticipate their movement.

3. Precise Gaze Patterns: Eye-tracking data confirmed that participants spent a significant amount of time fixating on the bubbles, with gaze patterns closely following their movements (Figure 3b and 3d). This validated that the bubbles were indeed effective attention-grabbing elements.

5 Conclusion

This paper highlights the potential of utilizing visually engaging elements like 3D-bubbles to enhance user experiences in VR. The observed physiological responses provide objective evidence that these elements can effectively capture attention, increase engagement, and potentially influence cognitive processes. This has important implications for VR Training; integrating similar visual cues into training simulations could help focus attention on critical information, leading to improved learning and retention. VR Therapy, by using strategically placed, visually stimulating elements, could be beneficial in therapeutic applications, such as attention training or anxiety reduction, by guiding the patients' focus and promoting a calming physiological state. VR Game Development by incorporating visually appealing objects can enhance the gaming experience by increasing engagement and providing players with intuitive visual cues.

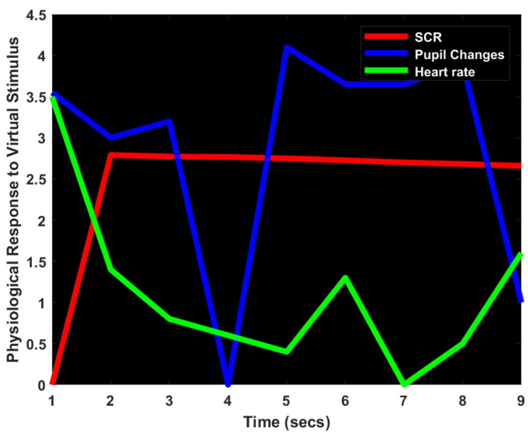
Further research is warranted to explore the long-term effects of these visual elements on physiological states and cognitive performance. It would also be beneficial to investigate how different types of visual stimuli, such as varying bubble sizes, colors, and movement patterns, impact physiological responses. Additionally, exploring individual differences in responsiveness to these stimuli could lead to personalized VR experiences that maximize engagement and effectiveness.

In conclusion, this study provides valuable insights into the physiological impact of 3D-bubble fixations in VR, demonstrating their effectiveness in capturing attention, increasing arousal, and influencing mental workload. As VR technology continues to advance, understanding how visual elements influence user experiences and physiological states is crucial for creating more engaging, effective, and personalized immersive environments.

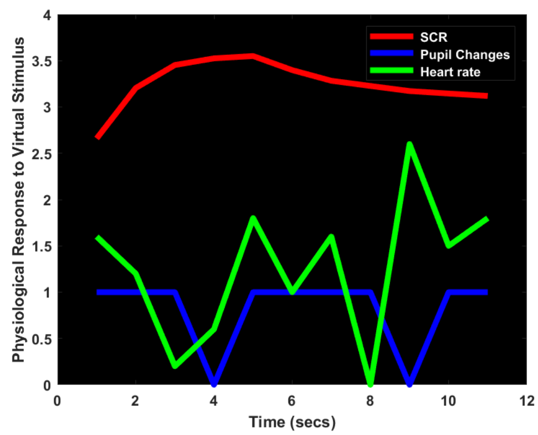
This type of research, while still evolving, highlights the immense potential of VR as a tool for understand-

(a) Virtual reality scene of first interphase.

(b) Virtual reality scene of second interphase.



(c) Physiological response to first interphase.



(d) Physiological response to second interphase.

Figure 2: Virtual reality scene correlating with physiological response for first and second phase.

ing and influencing human behavior and physiology. As VR technology continues to advance and become more accessible, we can expect to see even more innovative applications emerge, further blurring the lines between the virtual and the real world. Future studies could explore different types of virtual environments, varying levels of interactivity, and individual differences in physiological responses to further refine our understanding of how VR can impact the human experience on a deeply physiological level.

Acknowledgement

The authors would like to thank Nasarawa State University, Keffi, Nigeria, Department of Computing, Federal University of Dutse, Jigawa, Nigeria and the Department of Computing, Sheffield Hallam University, United Kingdom for their support and sponsorship of this paper.

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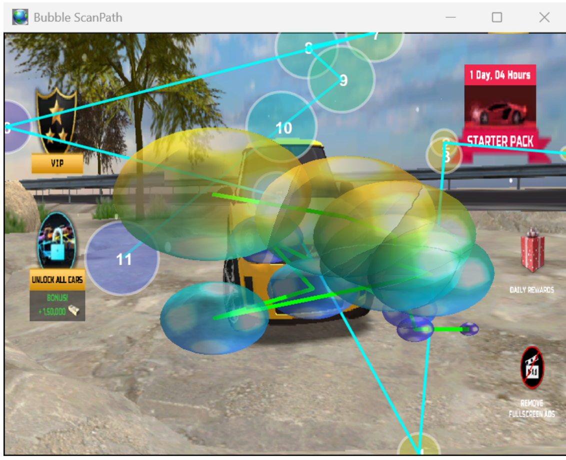
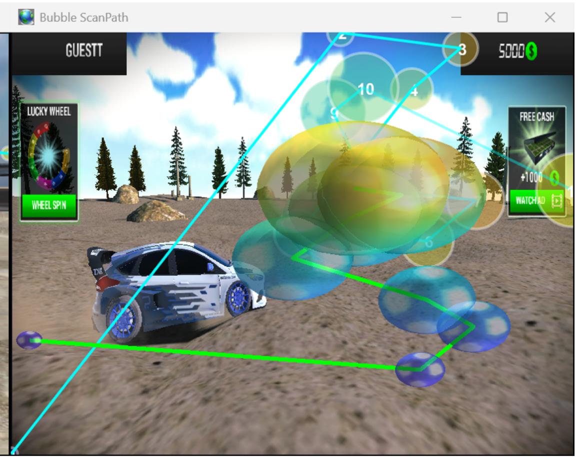
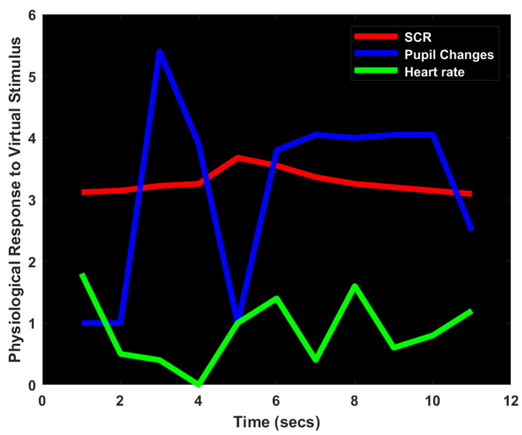


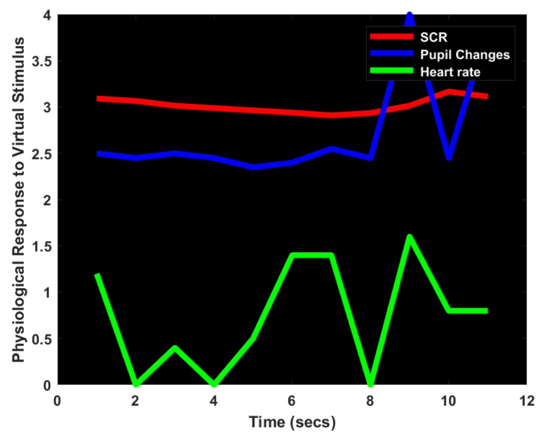
(a) Virtual reality scene of third interphase.



(b) Virtual reality scene of fourth interphase.



(c) Physiological response to third interphase.



(d) Physiological response to fourth interphase.

Figure 3: Virtual reality scene correlating with physiological response for third and fourth phase.

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