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Recommendations for Design Ergonomics in VR-based Cognitive Assessment Applications

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ABSTRACT

Cognitive assessment procedures tend to use virtual reality (VR) systems to create stimulating environments for task performance in an immersive virtual world. Therefore, the usability and well-being aspects that determine the effectiveness of these assessments are global ergonomic aspects. This research aims to fill this research gap by examining some of the most important ergonomic aspects, which have a direct impact on the validity and reliability of cognitive assessments in VR. We included literature related to the issue of cognition in immersive applications that presented the ergonomic aspects in question by performing a systematic review of the peer-reviewed literature on the topic, paying particular attention to the three strands of computer ergonomics: physical specifications (such as headset weight and balance), system-related specifications or organizational specifications (any aspect that informs us about system performance or user interface design), and cognition-related specifications (such as mental load and fatigue limits). In turn, by focusing on these ergonomic specifications, cognitive assessments in VR are envisioned to be more effective, comfortable, and accessible to a wider audience, thus improving their potential use in clinical and educational settings and providing reliable and valid results to therapists.

1. INTRODUCTION

Cognitive assessment has traditionally relied on standardized paper-and-pencil tests, role-playing, or clinical interviews. While these methods have provided valuable insights, they are more theoretical and canonical than practical. They often lack ecological validity, meaning that they do not necessarily reflect how people use their cognitive skills in real-world contexts [1]. Virtual reality (VR) technology offers a revolutionary approach to cognitive assessment, creating immersive environments that simulate real-world tasks and situations with infinite possibilities for configuration and parameterization [2]. This immersive nature of VR holds great promise for overcoming the limitations of traditional methods and providing a more ecologically valid assessment of cognitive functions. However, to fully exploit the potential of cognitive assessments in VR, well-defined ergonomic constraints must be specified and implemented during the design of the application and its deployment. These constraints serve as essential guidelines for building VR environments that prioritize user comfort and safety while improving cognitive performance and the validity of the final test result. They address factors such as minimizing physical strain, reducing the likelihood of cybersickness, and managing cognitive load to avoid overload and distract the user from fully focusing on their assessment. By focusing on user-centered design elements, ergonomic constraints help create VR experiences that produce accurate and meaningful cognitive data.

This article examines the key elements of ergonomic constraints in VR cognitive assessments. We explore how these constraints shape the VR experience, ensuring that it remains physically comfortable, accessible, and effective in reducing strain, fatigue, and cognitive overload.

The remainder of this article is organized as follows: we discuss the research methodology in the second part. In the following sections, we detail

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the three aspects of ergonomics with the precise specifications of each aspect, and we end with a conclusion.

2. RESERCH AND FINDINGS

The objective of this research is to identify ergonomic specifications for Virtual Reality (VR) applications used in cognitive assessment. To achieve this, we are reviewing studies related to VR, cognition, and the effects of VR on users. Findings are classified into three main categories: physical, system-related, and cognition-related specifications:

3. PHYSICAL SPECIFICATIONS

Physical specifications refer to the design and comfort aspects of VR systems that affect the user's physical well-being during cognitive assessments. These include:

3.1. Cybersickness and Visual Fatigue

Cybersickness, characterized by symptoms such as nausea, dizziness, and headaches, can significantly impact user performance and comfort in VR environments [3], [4]. Additionally, studies show that shorter assessment sessions and regular breaks help reduce visual fatigue. Recent findings suggest that adaptive lighting and minimizing visual clutter can also alleviate these issues. Both studies [5] and [6] address cybersickness, fatigue, and dizziness as ergonomic issues that need to be managed during prolonged VR use.

3.2. Headset Weight and Balance:

Research indicates that the weight and balance of head-mounted displays (HMDs) significantly affect physical fatigue and user discomfort during extended VR use. Heavier and imbalanced headsets increase the strain on the neck joints, causing greater physical discomfort. Ergonomic designs should focus on reducing weight and improving the balance of headsets to mitigate fatigue and discomfort during long sessions [7]. Study [5] highlighted discomfort caused by headset designs, which can be mitigated by using replaceable headbands and facial interfaces to enhance user comfort and hygiene.

3.3. Musculoskeletal Comfort

The ergonomic design of VR headsets and controllers is crucial to prevent physical discomfort, which can impact the accuracy of cognitive assessments. In Study [8], properly adjusted headsets with straps were shown to reduce facial pressure, improving comfort during long sessions.

3.4. Seated Positioning

To reduce postural strain during extended use, participants in Study [9] were seated in swivel chairs that provided support and comfort, an important ergonomic consideration for maintaining user comfort.

3.5. High-Resolution Headset

High-resolution headsets, as noted in Study [10], can significantly reduce visual strain, contributing to physical comfort and preventing eye fatigue. As we move from the physical specifications that enhance user comfort to the technical aspects of VR systems, it is essential to consider how these system-related specifications play a vital role in ensuring a seamless user experience.

4. SYSTEM-RELATED SPECIFICATIONS

System-related specifications focus on the technical performance and user interaction design of VR systems, which are essential for smooth operation and a positive user experience. Key factors include:

4.1. System Performance

High system performance, including low latency and high frame rates, is essential for a seamless VR experience. Poor performance can increase cognitive load and lead to cybersickness. Rizzo and Koenig [11] demonstrated that reducing system latency significantly improved user performance in cognitive VR tasks, thereby reducing the chances of cybersickness and improving the overall user experience [11].

4.2. User Interface and Interaction Design

Intuitive and user-friendly interfaces are essential for ensuring effective cognitive assessments in VR environments. Poor interface design can frustrate users, leading to inaccurate results [12]. Best practices include clear visual cues, providing timely feedback, and simplifying navigation. Using natural interaction methods such as hand gestures or voice commands can improve user experience and reduce cognitive load. For instance, Makransky et al. [13] found that using voice commands significantly reduced cognitive load compared to traditional navigation methods. Ergonomically positioning visual targets and interaction points can also reduce physical strain and improve overall usability [7]. Study [5] shows that VR setups with simplified hand controllers, where all buttons perform the same action, demonstrate ergonomic design, reducing cognitive load and physical strain.

4.3. Postural Support

Ergonomic positioning, as highlighted in Study [9], ensures users are seated comfortably to allow for head and body movement without causing strain.

4.4. Field of View & Head Movement

In Study [9], the inclusion of a wide field of view (FOV) and six degrees of freedom (6DOF) enhances user experience and minimizes ergonomic risks like neck strain, making it easier for users to interact comfortably with the VR environment. Having established the critical role of system-related specifications, we now turn our attention to cognition-related specifications, which focus on managing mental load to enhance the accuracy and effectiveness of cognitive assessments in VR environments.

5. COGNITION-RELATED SPECIFICATIONS

Cognition-related specifications focus on managing mental load to enhance the accuracy and effectiveness of cognitive assessments in VR environments. These specifications emphasize:

5.1. Cognitive Load Management

High cognitive load from complex tasks or poor design can negatively affect the accuracy of cognitive assessments. Simplifying user interfaces, reducing task complexity, and offering clear instructions are effective strategies for managing cognitive load. Using familiar and intuitive interaction methods can also reduce mental overload [14]. Studies show that reducing the physical strain from HMDs can further minimize cognitive load and improve overall task performance [15]. In Study [9], careful design considerations were made to minimize unnecessary strain on users.

5.2. Fatigue in Long-term Use

Studies on ergonomic design emphasize the importance of positioning virtual objects within a comfortable range of view to reduce biomechanical strain on the neck and shoulders, especially during long VR sessions. These adjustments not only reduce physical fatigue but also enhance cognitive task performance [7]. Moreover, integrating breaks every 15–20 minutes can aid in cognitive recovery and prevent fatigue during assessments.

5.3. Visual and Cognitive Aftereffects

Study [16] highlights how prolonged VR use can lead to visual and cognitive aftereffects, such as slower reaction times. These issues require ergonomic considerations to avoid long-term strain.

5.4. Safety from Overexertion

Designing VR environments that prevent physical overexertion, as discussed in Study [10], helps avoid strain or injury during use. We have collected the specifications extracted from our research and categorized them into four main areas: Visual Comfort, Physical Comfort, User-Friendly Interfaces, and Cognitive Load. The diagram below (Figure 1.) illustrates these ergonomic specifications for VR applications in cognitive assessment, highlighting their interconnected roles in enhancing user experience and performance.

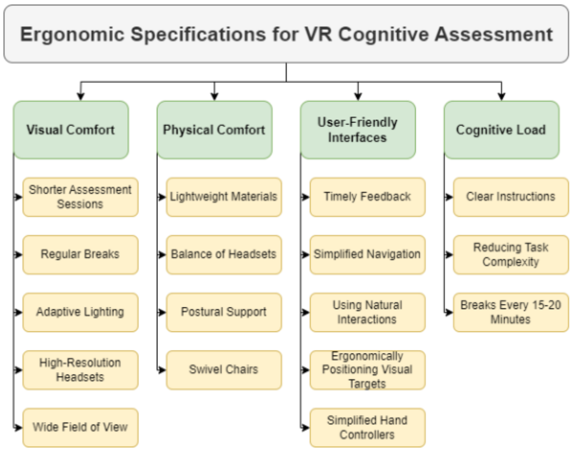

Figure 1. Classification of Review Studies Ergonomic Constraints

6. CONCLUSION

These physical, system-related, and cognition-related specifications are closely linked in the context of cognitive assessments within VR environments. For instance, poor ergonomic designs, such as imbalanced headsets or suboptimal user interfaces, can lead to increased physical discomfort, which, when combined with high cognitive load, can exacerbate user fatigue and reduce assessment accuracy. Optimizing system performance, interaction design, and ergonomic factors not only improves physical and cognitive comfort but also enhances the overall accuracy and reliability of VR-based cognitive evaluations.

Conflict of Interest

No conflict of interest is declared by the authors. In addition, no financial support was received.

Author Contributions

Study Design, BB, AM, SSB; Data Collection, BB; Data Interpretation, BB, AM, SSB; Manuscript Preparation, BB; Literature Search, BB, AM, SSB. All authors have read and agreed to the published version of the manuscript.

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