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The Effect of Cognitive Load on Visual Search Tasks in Multisensory Immersive Environments

Jorge Pina* Edurne Bernal-Berdun Daniel Martin Sandra Malpica Carmen Real
Pablo Armañac-Julián Jesus Lazaro Alba Martín-Yebra Belen Masia Ana Serrano

Universidad de Zaragoza - I3A, Spain

ABSTRACT

Cognitive load, the mental effort required to process information and perform tasks, affects user performance and engagement. Understanding its impact in immersive, multisensory experiences is critical for task-oriented applications like training and education. We studied the effect of cognitive load on user performance on a visual search task, performed on its own or alongside a secondary, auditory task. This effect was tested for two different search areas: 90º and 360º. Results show a decline of task performance with increased cognitive load, but with different trends between the 90º and 360º cases.

Index Terms: Virtual reality, Cognitive science, Perception, User studies.

1 INTRODUCTION

The study of cognitive load (CL) has been an active area of research [11, 10, 4] since the publication of the seminal work from John Sweller [9], which established the basis of the cognitive load theory. This theory conceptualizes CL as the amount of cognitive resources allocated to completing a specific task, and provides a framework for understanding how the presentation of information influences CL. High levels of CL have been considered detrimental to the user's experience and performance, and understanding and minimizing these effects has become a key focus of CL theory research [5].

Several studies have explored how CL can influence task performance across different digital media [12, 8]. However, much of this research focuses on media where user interaction is constrained to fixed viewpoints or to a reduced field of view; this differs from immersive environments such as virtual reality (VR), which allow exploration of a 360° scene.

Additionally, VR is multisensory, combining visual, auditory, and sometimes haptic stimuli to create highly immersive experiences. While these features enhance engagement, they also increase the risk of sensory overload [1, 7]. Despite the unique multisensory demands of VR, relatively few studies have investigated how CL affects visual search tasks in such environments, with most research focusing on specific areas, like learning or navigation [2, 3].

In this work, we study how CL induced by multisensory inputs affects task performance in visual search, both in the case of 90º and 360º search areas. To investigate this, we designed an experiment inspired by the work of Das et al. on traditional displays [6], adapting it to immersive environments and extending it. Our study includes two main factors: *cognitive load* and *search area*. Cognitive load was manipulated by having participants perform either a visual search task alone, or combining it with an auditory task. Search area was varied between a 90° environment, where the search was confined to a limited field of view, and a 360° environment, requiring exploration of the entire scene. This work adds to the growing body of research on multisensory CL, offering an initial exploration of its effects on task performance in immersive environments.

*e-mail: jpinac@unizar.es



Figure 1: Isometric view of the room designed for the experiment. Participants were positioned at the center of the square room with objects across all four walls for the 360º condition or just one for the 90º condition. The inset shows an example of a target object.

2 EXPERIMENTAL DESIGN

Hardware and participants: We used a Varjo XR-4 headset (120º×150º FOV, 90 Hz, 3840×3744 resolution, 51 PPD) and recruited 10 participants (5 female, 5 male, ages 22 to 38) with normal or corrected-to-normal vision and hearing. Written consent was obtained, and the protocol was approved by our institution's ethics committee.

Conditions and tasks: We explore two factors: *cognitive load* and *search area*. The former had two levels: low (LCL) and high cognitive load (HCL). In LCL, participants performed only a visual search task, locating objects highlighted in golden within the scene (Fig. 1) and selecting them with the trigger of the Varjo controller. In the HCL case, participants completed the same visual search task while simultaneously performing a secondary auditory task, identifying odd numbers in an audio recording by pressing the A button in the Varjo controller. The search area factor also had two levels: 90°, where the objects would appear within a limited section along one wall of the room (and participants were informed of this), and 360°, which required participants to rotate their view and explore the entire scene. The experiment had a full factorial design, with $2 \times 2 = 4$ conditions, and one so-called trial per condition. Each trial had a fixed duration of 4 minutes, during which participants searched for objects within the specified search area while also performing (or not) the auditory task.

Procedure: The experiment consisted of two blocks, one for 90º and one for 360º configurations. Block order was fixed, starting with 90º, so that participants became familiar with the simpler environment before progressing to the 360º search area. Within each

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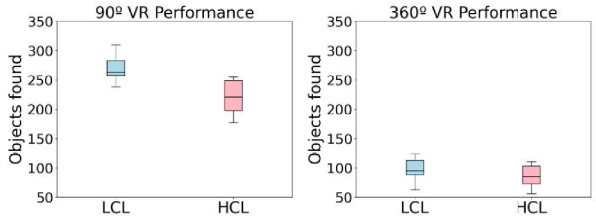


Figure 2: Main task performance across segments. Results for the 90º (left) and 360º (right) search areas. Each boxplot compares the number of objects found under the low and high CL conditions.

block, participants completed the LCL and HCL conditions in random order. The experiment began with a 4-minute relaxation stage, and 2-minute relaxation stages were included between conditions and blocks. Total duration was circa 30 minutes.

3 Results

During each 4-minute segment, we tracked all button pressings to compute performance metrics for both the primary and secondary tasks. Performance on the primary task, a visual search, was measured as the number of golden objects successfully located and selected within the scene. Performance measurements from the secondary task were also analyzed to confirm that participants allocated cognitive resources to it and did not prioritize the primary task at its expense. Specifically, for each odd number in the audio recording, button pressings within a 3-second window of its onset were considered successful. False positives (button pressings in the absence of an odd number) and false negatives (missed odd numbers) were also computed. Reaction times for correctly identified odd numbers were also calculated as the time elapsed between the onset of the word and the participant pressing the A button.

While direct comparisons between the 90º and 360º search areas were not conducted due to their fixed order, we analyzed trends by comparing LCL and HCL within each configuration to observe whether their effect differs across search areas. Normal distribution of the data was checked with the Kolmogorov-Smirnov test. Homogeneity of variances was tested with an F-test. The normality and equal variances assumptions were met. T-tests were used to check for significant differences between conditions.

As shown in Fig. 2, performance on the main task decreases consistently during HCL segments compared to their LCL counterpart, showing the impact of higher cognitive load introduced by the secondary auditory task on the primary visual search task. This effect is significant ($p=0.0005$, $t=4.2357$) in the 90º configuration, where the number of objects found drops considerably under HCL. In the 360º configuration, while performance is overall lower due to the increased difficulty of exploring a larger search area, the difference between LCL and HCL is non-significant ($p=0.2006$, $t=1.3284$). In the 90º configuration, the focused search area may allow participants to perform well under LCL but makes them more susceptible to performance degradation under HCL. By contrast, the inherently higher demands of the 360º configuration may leave participants with fewer resources to allocate to the primary task from the start, reducing the relative impact of the secondary task. However, the fixed order of the search area conditions should be taken into account, as this tendency could be affected by factors such as learning or fatigue.

Tab. 1 summarizes performance metrics for the secondary task (present only in HCL) for the 90º and 360º configurations. High accuracy rates, low false positives, and reaction times under 2 seconds suggest that participants actively engaged with the task.

Table 1: Performance metrics for the secondary task in the 90º and 360º configurations. The values are presented as the mean across participants, with the standard deviation (SD) shown in parentheses.

	90º Condition	360º Condition
Precision	86.74% (11)	85.65% (8)
False Positives	7.64% (1)	11.26% (3)
Mean Reaction Time (ms)	1,174 (149)	1,145 (156)
Reaction Time STD (ms)	506 (67)	506 (93)

4 Conclusion

In this work, we examined how multitasking across sensory modalities increases CL in immersive environments. Our results suggest that high CL reduces performance by straining limited cognitive resources, yet they are still preliminary and require further exploration. Future studies could explore strategies to mitigate this effect and improve VR experiences. Moving forward, we plan to incorporate subjective CL measures (e.g., NASA-TLX) and identify objective markers, such as eye-tracking data or physiological responses, to better predict this behavior.

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