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Guiding Attention in VR: Comparing the Effect of Peripheral and Central Cues on Presence and Workload

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Resumo

As aplicações de realidade virtual (VR) exigem, cada vez mais, técnicas eficazes de orientação da atenção para ajudar os utilizadores a concentrarem-se nas informações mais relevantes nos ambientes virtuais imersivos (IVEs). Embora as pistas visuais centrais se tenham revelado eficazes para orientar a atenção, frequentemente comprometem a imersão e a sensação de presença do utilizador. Este estudo investigou se as pistas visuais periféricas poderiam servir como uma abordagem alternativa que mantém a eficácia da orientação da atenção, simultaneamente preservando a sensação de presença.

Foi realizada uma experiência com 24 participantes, utilizando uma aplicação de VR personalizada que testou quatro pistas visuais distintas: duas pistas centrais (Floating Text e Floating Arrow) e duas pistas periféricas (Edge Lighting e Swarm). Os participantes completaram tarefas em sete rondas para cada tipo de pista, sendo o desempenho medido através do tempo de reação, tempo de ronda e número total de erros cometidos. A sensação de presença foi avaliada com o IGROUP Presence Questionnaire (IPQ) e a carga de trabalho foi avaliada com o NASA Task Load Index (NASA-TLX). As preferências subjetivas dos participantes também foram recolhidas através de um questionário de classificação de pistas no final da experiência.

Os resultados revelaram que a eficácia da pista foi determinada principalmente pelas caraterísticas do desenho e não pelo seu posicionamento no espaço. As pistas bem concebidas obtiveram um desempenho superior, independentemente do seu posicionamento central ou periférico, com a Floating Arrow (central) e o Swarm (periférico) a demonstrarem uma eficácia comparativamente elevada. No que respeita aos níveis de presença, não foram encontradas diferenças estatisticamente significativas entre as pistas periféricas e centrais, em qualquer dos componentes de presença do IPQ. No entanto, o impacto na carga de trabalho variou significativamente com base na implementação de cada pista específica e não na categoria de posicionamento da mesma.

Os resultados desafiam o pressuposto de que o posicionamento periférico proporciona vantagens de orientação da atenção em relação ao posicionamento central. Em vez disso, a conceção cuidadosa da pista parece ser o fator crítico para conseguir uma orientação eficaz da atenção, preservando a sensação de presença em ambientes de VR. Estes resultados fornecem informações valiosas para designers de interfaces de VR, sugerindo que os recursos de desenvolvimento devem priorizar a criação de elementos de orientação intuitivos e bem concebidos, em vez de se concentrarem apenas em fatores de posicionamento espacial.

Abstract

Virtual Reality (VR) applications increasingly require effective attention guidance techniques to aid users in focusing on the more relevant information within Immersive Virtual Environments (IVEs). While central visual cues have proven effective for directing attention, they often compromise on user immersion, and presence. This study investigated whether peripheral visual cues could serve as an alternative approach that maintains attention guidance effectiveness while also preserving the sense of presence.

A controlled experiment was conducted with 24 participants using a custom-built VR application that tested four distinct visual cues: two central cues (Floating Text and Floating Arrow) and two peripheral cues (Edge Lighting and Swarm). Participants completed tasks across seven rounds for each cue type, with performance measured through reaction time, round time, and total errors made. Presence was assessed using the IGROUP Presence Questionnaire (IPQ), and workload was evaluated with the NASA Task Load Index (NASA-TLX). Participant subjective preferences were also collected through a post-experiment cue ranking questionnaire.

Results revealed that cue effectiveness was primarily determined by design characteristics rather than its spatial positioning. Well designed cues achieved superior performance, regardless of central or peripheral positioning, with the Floating Arrow (central) and Swarm (peripheral) demonstrating comparably high effectiveness. In regards to presence levels, no statistically detectable differences were found between peripheral and central cue alternatives in any of the IPQ presence components. However, workload impacts varied significantly based on specific cue implementation rather than cue positioning category.

Overall findings challenge the assumption that peripheral positioning inherently provides attention guidance advantages over central placement. Instead, thoughtful cue design appears to be the critical factor for achieving effective attention guidance while preserving presence in IVEs. These results provide valuable insights for VR interface designers, suggesting that development resources should prioritize the creation of intuitive and well-designed guidance elements, rather than focusing solely on spatial positioning factors.

AI Usage Disclosure

Artificial Intelligence (hereafter AI) tools have been utilized in this dissertation.

Perplexity AI has been used to brainstorm and develop parts of the structural framework of this thesis.

All AI-generated content was reviewed and validated for relevance, appropriateness, and accuracy before incorporation into the final manuscript to maintain scholarly integrity of this research.

The author takes full responsibility for the content of the document.

UN Sustainable Development Goals

The research conducted in this thesis aligns with several United Nations Sustainable Development Goals (SDGs) through its focus on cognitive workload optimization in virtual reality environments. This investigation also demonstrates measurable contributions to two key SDGs, by examining how different visual cue types affect participant performance, and mental demand.

SDG 3: Good Health and Well-being

Good Health and Well-being represents the primary contribution, through research that demonstrates how visual cue designs can significantly affect cognitive workload. Findings explore how different cue conditions can have substantial differences in mental demand, and how optimized visual elements may reduce cognitive burden and support psychological well-being during VR interactions. This may prove particularly relevant for some medical or therapeutic VR applications, and extended training sessions where sustained cognitive performance is critical.

SDG 9: Industry, Innovation and Infrastructure

This work provides evidence-based guidelines for VR application development, supported by the quantitative metrics and statistical validation. These methodological advances help innovation in VR technology infrastructure, and may contribute to the human-computer interaction design decisions, in Immersive Virtual Environments (IVEs).

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<Ricardo Pinto>

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List of Acronyms

ANOVA	Analysis of Variance
CC	Central Cue
FOV	Field of View
HMD	Head-Mounted Display
IPQ	Igroup Presence Questionnaire
IVE	Immersive Virtual Environment
NASA-TLX	NASA Task Load Index
PC	Peripheral Cue
UI	User Interface
VE	Virtual Environment
VR	Virtual Reality

Chapter 1

Introduction

1.1 Context

In recent years, Virtual Reality (VR) has undergone significant evolution and is now a popular platform for a multitude of applications, including training [52], entertainment [1], and even healthcare such as for occupational therapy to address anxiety disorders [13].

Immersive virtual environments (IVEs) have become intrinsic to these applications, and allow users to undergo deep sensory experiences and feel present in an alternative reality environment. One of the fundamental challenges in IVEs lies in the inherent limitation of human perception within a 360° virtual space. While these environments offer a complete spherical content, users are still constrained by their natural field of view (FOV), creating a perceptual bottleneck and hence spatial awareness problem, where important events, objects or context may go by unnoticed. This could compromise users' ability to fully comprehend and interact with the virtual environment effectively.

In a multitude of VR applications, users are required to concentrate on specific objectives and tasks within the virtual world, and if attention is poorly managed, users may get distracted and miss crucial information on-screen, affecting overall experience and task performance.

1.2 Motivation

As the software developed in VR expands into more complex domains, the challenge of effectively guiding user focus within Immersive Virtual Environments (IVEs) becomes paramount. Understanding how to optimize user attention via non-intrusive peripheral cues becomes increasingly important.

This significant limitation in user visual perception creates the need for user attention direction techniques within an IVE that do not overwhelm the user.

By focusing primarily on how peripheral cues impact user attention, while also considering some secondary effects, such as sense of presence and workload, this research addresses a critical gap in the understanding on how to effectively guide user attention without compromising on some of the value VR applications bring.

1.3 Problem

Typical attention guidance methods usually involve direct visual cues, present in the centre of the user's view which, although effective [48], can easily detract from the user's sense of immersion or even obfuscate important on-screen information.

A key challenge pertains to user attention guidance within IVEs, without reducing the feeling of immersion. The use of visual, and even auditory attention guidance techniques may prove effective in attention guidance but may overwhelm the user and hence decrease task performance, and overall tool effectiveness [24]. For example, a bright flashing icon in the centre of the screen is great at efficiently guiding the user's attention, but may be equally as intrusive.

The challenge lies in developing effective attention guidance techniques, that not only enhance user attention but also avoid overwhelming the user and hindering their focus. Furthermore, the effect of these techniques on the mentioned secondary effects, namely the sense of presence and workload, should also be considered.

1.4 Research Questions and Hypothesis

The research questions 1.4.1 and hypothesis 1.4.2 presented below guide the investigation into the effectiveness of peripheral visual cues for attention guidance in IVEs. These emerge from the identified need to balance effective attention redirection with the preservation of user sense of presence and manageable cognitive workload.

1.4.1 Research Questions

1. How effective are peripheral visual cues in drawing attention in IVEs compared to central cues?

2. How is the user's sense of presence and workload impacted by peripheral visual cues, in IVEs?

1.4.2 Hypothesis

1. Peripheral visual cues are effective in drawing user attention in IVEs without negatively impacting the sense of presence and workload, when compared to central visual cues.

Chapter 2

State of the Art

A contextualization and overview of the key concepts and research areas relevant to this project and to the topics it aims to investigate is provided in this chapter.

Firstly, an overview of the employed literature review methodology to establish the foundation for this research begins the discussion (section 2.1), outlining the approach used to identify and evaluate the most relevant studies in the field of attention guidance techniques, within VR environments.

Following this, the discussion on section 2.2 explores the concepts of Virtual Reality (VR) and Immersive Virtual Environments (IVEs), describing the technological advancements that have enabled widespread adoption of VR applications in society across various domains, and how they connect with human sense of presence and cognitive workload. This understanding and knowledge is essential, given the full investigation will surround the area of VR and IVEs.

Moreover, the following section 2.3 is dedicated to the exploration of attention as a cognitive mechanism in humans. This topic is relevant to this research given it directly pertains to the hypothesis and first research question. Following that, the different types and components of attention are identified and explored, and ending with the impact of attention in the context of VR and IVEs.

The subsequent section 2.4, reviews the several different attention guidance techniques in the context of VR, and current knowledge about them as demonstrated by several research papers. Specifically, central visual cues, peripheral visual cues and multimodal approaches are explored. The importance of these examinations are due to the fact the first research question revolves around comparing central with peripheral visual cues and its impact on user attention, and the second research question pertains to the impact of peripheral visual cues. Furthermore, multimodal approaches were also investigated to provide additional context for the study, as their strengths and limitations may offer valuable insights for evaluating purely visual attention guidance techniques.

Finally, this chapter's research relevance is discussed in the final section 2.5, showcasing what areas could benefit from further exploration and studies, and how this research can improve the domain of attention guidance, presence and workload within the domain of Virtual Reality and IVEs.

2.1 Literature Review Approach

To establish the foundation for this research, a comprehensive literature review was conducted, using a narrative review approach. This methodology was chosen due to its flexibility and efficiency in exploring the inter-disciplinary nature of attention guidance techniques in VR environments.

The literature search strategy employed various academic databases including IEEE Xplore, Springer Nature Link, ACM Digital Library, and Google Scholar. Search queries combined keywords such as "Virtual Reality", "Immersive Virtual Environment", "Peripheral Cues", "Central Cues", "User Attention", and "Presence" to capture relevant research papers across computer science, engineering, and human-computer interaction domains.

The screening process required papers to address at least two core topics from a list made up of "attention guidance", "task performance", "workload", "presence", "visual/auditory cues", and "cognitive load". Priority was given to studies with empirical foundations, high number of citation, and robust approaches to their methodology implementation. This approach yielded 59 relevant papers, reports, and articles, and provided a comprehensive foundation for understanding current knowledge in attention guidance techniques in IVEs.

2.2 Virtual Reality (VR) and Immersive Virtual Environments (IVEs)

Virtual Reality (VR) and Immersive Virtual Environments (IVEs) have fundamentally changed how everyday users interact with digital content. It introduced the world to engaging audio-visual experiences, and are arguably the closest we have been to engaging in real-world activities, in a simulated digital format. Modern VR and IVE equipment combines high performance hardware and highly specialized software adapted for the VR context they are in, such as for entertainment [1], employee workplace training [52] and for healthcare purposes [13]. As this technology evolved, so did the research on specific aspects of computer human interaction related to VR, such as presence and workload.

2.2.1 Presence in Virtual Reality

The concept of presence, as outlined by Slater and Wilbur in 1997, is defined as "a state of consciousness that may be concomitant with immersion, and is related to a sense of being in a place." [43]. The sense of presence is arguably one of the most important aspects to preserve within the context of Virtual Reality and IVEs, given multiple studies have consistently reported a clear correlation between the sense of presence and emotional experiences within this context [39], [35], [38], [8], [36]. The importance of such correlation lies in the benefits of providing emotional experiences to users.

Additionally, a wide variety of emotions experienced by participants and specific types of affective content have been directly linked with a sense of presence, including both positive and negative emotions [4], [5]. The 2004 study compared three immersive systems (PC monitor, projected video, and HMD) and two virtual environments (one with and one without emotional content), and found affective content to have an impact on presence [4]. This reveals the fundamental relation between the feeling of presence that virtual reality can induce on humans, and how powerful it may be.

All-in-all, the importance of these findings lie in their ability to enable emotional experiences and natural behaviours within IVEs. The possible applications of these methods involve countless major fields, such as healthcare, where VR has been successfully employed for exposure therapy for phobias and PTSD [13] and anxiety management through immersive relaxation environments [39]. Another example would be education and training, where a realistic virtual environment helps provide an experience as close to reality as possible, and where reactions that correlate to how the user would react in a real world scenario, is desirable. Finally, the entertainment industry is also a good candidate field, where emotional and natural interactions could output more immersive and engaging experiences that resonate with users on a deeper level.

2.2.2 Workload in Virtual Reality

Workload refers, in this context, to "the mental resources needed by an individual to perform and complete a given task" [50]. Cognitive workload is a fundamental consideration in the evaluation of Virtual Reality (VR) and Immersive Virtual Environments (IVEs) design choices, and becomes particularly complex within these contexts due to the immersive nature of these systems. As VR and IVEs create increasingly complex and information-rich environments, understanding how these impact cognitive resources becomes essential for optimizing both performance and participant well-being [6]. This is especially important in specific use cases, such as education, where high mental workload in immersive educational experiences is proven to have negative effects on students' learning experiences [10]. An experiment carried out by a recent 2024 study, where the use of VR technology as a support tool in the higher educational model was analysed, concluded that "if students experience feelings of overwhelm or frustration, they are less likely to retain information and improve their learning." [10], clearly demonstrating the undesirable impact excessive workload can have in VR and IVEs. These systems require participants to simultaneously process multisensory information presented to them, navigate in 3D spaces, interact with implemented virtual objects, and manage the additional cognitive demands imposed by the technology itself [28], [42].

Given the importance of measuring and assessing cognitive workload in VR environments, the development of dedicated specialized evaluation techniques emerged, with the NASA Task Load Index (NASA-TLX) [32] being widely considered as the standard subjective measurement tool across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration [9], [30], [32]. Given its widespread adoption for this topic, research has consistently shown that the NASA-TLX maintains its effectiveness even within VR environments, and shows reliable correlations between subjective workload scores, and objective performance measurements [31]. Other physiological indicators, including pupillometry and eye-tracking metrics, have also shown strong correlations with cognitive load measures using the NASA-TLX, in complex VR scenarios [33]. This observed relationship between performance and workload in

VR environments reveals that, while some levels of cognitive load can enhance engagement and even learning outcomes, excessive cognitive workload usually leads to a significant degradation in performance and overall participant satisfaction [10]. Furthermore, the complexity in representation of certain visual elements in VR also appears to have an impact on workload: one 2023 study showed that using an excessively detailed avatar representation, although increasing the "sensation of being there", can also increase extraneous cognitive load and impair task outcomes [29]. Some studies have gone as far as analysing the effect of attentional-guidance cues on workload, and found that VR learning environments that employ said cues not only reduce cognitive workload, but also yield higher academic performance [51].

2.3 Exploring Attention as a Cognitive Mechanism

Given the vast amounts of information humans consume as input from the five main senses, the ability to filter out and focus on a specific subset of information is critical. This human ability is commonly referred to as attention, and plays an important role due to humans' limitation in consciously processing all information in an effective and simultaneous manner.

2.3.1 Types and Components of Attention

The cognitive mechanism of attention in humans is complex in nature and difficult to fully describe, and has therefore long been studied in an attempt to break it down into multiple types and subcategories of attention. A 2001 paper breaks down attention into voluntary and automatic attention [18], and further exemplifies these concepts using humans' ability to feel temperature information from both our feet, individually. For example, we can at any point decide to focus on our right foot's temperature (voluntary attention), but if for some unexpected reason, our left foot becomes too hot, or cold, our brain focuses its attention on it (automatic attention) [18].

In addition to the types of attention, multiple studies classify attention into its constituent components. In 1971, a physiological review suggested a subdivision of the concept of attention into the three main components known as alertness, selectivity, and processing capacity [34]. Posner and Boies referred to the *alertness* component as the general state of readiness for input information processing tasks, the *selectivity* component as the ability to select the focus on a specific stimuli whilst simultaneously mentally discarding others, and *processing capacity* component as the capacity, or ability, to process encoded information using mental operations, such as response selection or memory rehearsal. This research further concluded that alertness and selectivity were able to operate independently without interference with one another, whilst highly demanding mental tasks requiring significant amounts of cognitive resources would cause processing capacity to become a bottleneck, and hence interfere with tasks at hand.

Furthermore, the theorized components that make up attention have evolved over time, with a more recent study carried out in 2007 identifying "Four processes [...] fundamental to attention: working memory, top-down sensitivity control, competitive selection, and automatic bottom-up filtering for salient stimuli" [23]. The author, Knudsen, described *working memory* as a mental workspace for temporary storage and processing of selected information, *top-down sensitivity control* as a signal strength adjuster, based on task priorities and/or goals, *competitive selection* as the filtration of which external information is able to enter working memory, and finally, *automatic bottom-up filtering for salient stimuli* as the ability to automatically highlight stimuli deemed rare, unexpected, or of otherwise biological importance [23]. Understanding these fundamental attention processes is crucial for designing effective guidance techniques within VR. Attention guidance techniques should consider these mechanisms to successfully direct attention, without overwhelming the competitive selection process, or disrupting working memory operations.

2.3.2 Human Attention Relationship with VR and IVEs

The cognitive mechanism attention is also relevant for human-computer interaction (HCI), including in the context of VR and IVEs. As technology, hardware and software in this field develops, the amount of information humans can engage with becomes increasingly alike to that of the real world [52]. IVEs offer 360° spatial environments, and consequently, vast amounts of additional information to users when compared to more traditional technologies, such as 2D screens. As discussed previously in this section, humans are somewhat limited in terms of the amount of information they are able to process simultaneously, and use attention as a way to focus on what is deemed more relevant and important from the full environment [23]. Attention, or in other words what to focus on at what times, becomes progressively more important as the amount of information provided by modern VR technology increases [40].

A 2022 study that aimed to investigate the use of virtual reality on students for attention training helped understand the benefits within the field of education, as it concluded that the student's attention was improved significantly when VR systems were used, when compared to regular computerized Attention Process Training (APT) [47]. In the field of healthcare and rehabilitation, VR technology has also proved beneficial. Examples include its successful outcomes in increasing the visual attention of patients who suffered cerebrovascular accidents [11], or the identified opportunities for improving cognitive functions, such as attention, on children suffering from attention deficit hyperactivity disorder (ADHD) [3].

All things considered, the importance of attention is clear within the field of VR and IVEs. However, relying only on natural human attention mechanisms may prove insufficient for users to effectively focus on the relevant on-screen elements, specially within complex IVEs, creating the need for dedicated attention guidance techniques.

2.4 Attention Guidance Techniques in VR

We can take advantage of the fact that IVEs are fully digitally generated to implement mechanisms that help humans direct attention to certain target objects, or tasks, within that virtual environment.

This concept is denominated as attention guidance techniques, and the premise lies on manipulating the information within the IVE in such a way that the relevant information is communicated to the user effectively, and consequently redirects their attention to the target.

We can group the types of attention guidance techniques previously explored into ones that involve central visual cues, peripheral visual cues, and multimodal approaches. Central visual cues involve visual elements that appear prominently near, or in, the centre of the user's field of view (FOV), whilst peripheral visual cues are displayed near the edges of the user's view, and as the name implies, are related to human's peripheral vision ability. Finally, multimodal approaches are ones where the combination of both visual and non-visual cue elements are implemented, such as auditory signals or vibrotactile approaches.

2.4.1 Central Visual Cues

Among the many VR attention guidance techniques identified during this study's literature review process, central visual cues emerged as one of the more explored and documented approaches. As previously mentioned, central visual cues can be described in this research context as cues that explicitly and deliberately guide a user's attention using visual elements that appear within their central vision area.

Implementations of these types of central cues are often hypothesized to be used for direct and voluntary user attention [40]. These cues can range from a variety of visual elements, such as icons, highlights, glows, or even plain text in the centre of the screen. One of the more common types of visual elements used for this purpose are arrows, as shown by Soret et al. [44].

Figure 2.1: Example of arrow central visual cue [44]

Having these types of visual cues present can improve task performance metrics, such as reaction time, and do prove effective in guiding a user's attention to the correct location within an IVE [44]. Although the direct nature of this approach gives it high effectiveness on guiding user attention, these types of central visual elements are not the best in preventing cyber-sickness, nor in optimizing for engagement and enjoyment, as shown in a 2019 research paper [48]. Participants would watch a 360° video, where actors would engage in conversation regarding different topics, such as a virtual field trip. The two compared attention guidance methods were central visual cues, represented by an arrow on screen, and a more natural guidance system named the Action Unit (AU) system [48]. In the AU system, the video actors would point, look and talk about the target, prompting the user to shift their attention to the target. This technique involved no digital element overlay of the video being displayed, and was naturally embedded in the content being displayed, which reduced visual clutter. However, this approach has significant limitations as it requires pre-planned content creation with trained performers, and cannot be dynamically adjusted based on user behaviour, which severely limits its usability and scalability in broader VR applications.

Another common form of central visual cueing is the use of simple textual elements, similar to the ones used in a 2023 research paper [2].

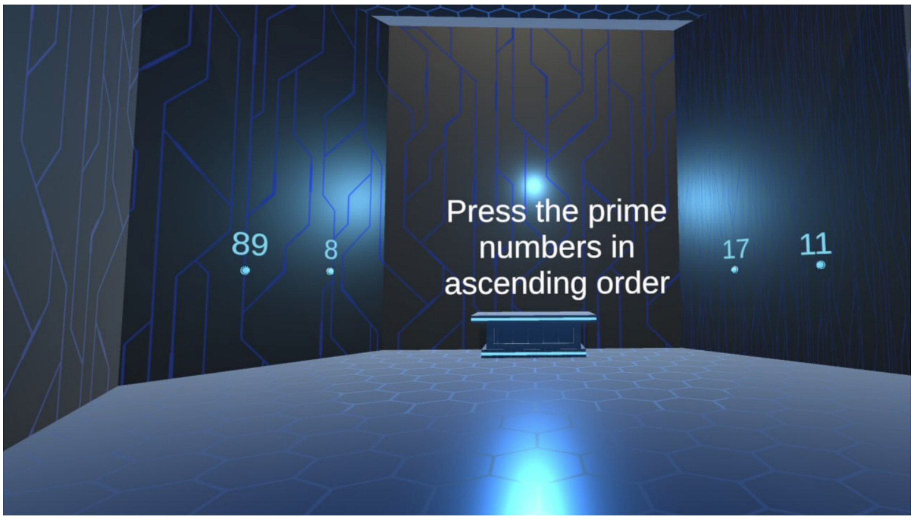

Figure 2.2: Example of text-based central visual cue [2]

The study's experiment, shown in the above Figure 2.2, compared four different attention guidance strategies: Text Effects (visual changes to text like rotation or scaling), Pointer (visual arrow pointing towards the targets), Audio Cues (guidance via spatial sound), and Following Text (text kept within the participant's FOV). Most participants in this study ranked textual cues lower than alternative attention guidance techniques explored in the study, such as the Pointer and Audio Cues. However, participants found some of the textual elements in the experiment to be obnoxious and participant feedback suggested that the user's interface felt cluttered at times [2]. The study's experimental results showed task performance peaked for some participants when using the simple text effect element for guiding a participant's attention to the target content, when compared to the other three guidance methods tested, indicating that the use of these cues can be effective at attention guidance. However, the implementation of these types of textual elements is important, as some variations did better than others.

These findings once again support the idea that the use of these types of cues can effectively guide a user's attention and achieve high levels of task performance, but if badly implemented or managed can just as easily become cumbersome and overwhelming for users, ultimately hindering overall experience.

Furthermore, another common issue that arises from the use of central visual cue approaches is its negative impact on immersion and consequently the feeling of presence, as demonstrated by Lange et al. and Krekhov et al. in their studies:

Lange et al. studied this phenomenon with their research paper on the development of HiveFive, a technique in which user attention is guided using directional cues and what the researchers call "swarm motion" [27]. This technique involved using a swarm-like biological, and non-biological movement of particles around a target object to guide user attention to it. HiveFive was compared to other attention guidance techniques, including an arrow near the target object, and blurring the surrounding scene with exception of the target object itself. It was also compared to a technique developed by Krekhov et al. named DeadEye (where the target object is only rendered in one of the two lenses, usually on the dominant eye) [25]. Findings indicate that not only did HiveFive outperform all other techniques with the exception of the arrow in regards to task performance (as indicated by the Time to First Fixation (TTFF) performance metric), but it also managed to "induce the lowest amounts of mental, physical and temporal demand, as well as the lowest effort and frustration" [27] from all tested techniques, based on the NASA Task Load Index (NASA TLX) results.

The reasoning behind these findings, as explained by the authors, could have to do with a few reasons; regarding task load, HiveFive employed diegetic stimuli (visual cues that are perceived as natural parts of the virtual environment, rather than artificial overlays). The diegetic nature of stimuli provided by HiveFive (when compared to Arrow), and how it was perceived as "well integrated into the scene" [27] may suggest that HiveFive and its swarm technique offer a more natural attention guidance method. Furthermore, and regarding the sense of presence, Lange et al. theorize that HiveFive's ability to guide attention while maintaining the sense of presence had to do with the way in which attention was generated. More specifically, alternative methods (Arrow, Subtle Gaze Direction, Blurring and DeadEye) generated attention via "artificial stimuli while manipulating the scene" [27], a stark contrast to HiveFive and its adequate embeddedness into the virtual environment.

A more recent 2023 study carried out by Doerr and colleagues aimed to explore the effect of both static and dynamic visual distractors on some of the existing attention guidance techniques [12]. These visual distractors included moving objects such as bees, animated swarms, and other "nature-based" moving phenomenons, while static distractors consisted of similar objects to the target (such as other apple trees) and other non-moving environmental elements, like flower beds. To explore the effect of these distractors, the study compared completion times, mental demand,

and effort of users when using HiveFive against other techniques, including the circle, where a simple circle bordering the target object was rendered. Results revealed that HiveFive underperformed the circle technique in term of completion time, mental demand, and effort, especially if the distraction type was dynamic. These findings show how some of the positive effects of visual guidance techniques fade away when visual distractors are present in the IVE scene, which depending on the context, could be quite common. The use of more powerful guidance techniques such as the circle, or the arrow, may compensate for this but as explained previously, could hinder on the feeling of presence.

Overall, these findings clearly show there is ground for further exploration on how the negative effects of attention guidance in VR and IVEs could be reduced, specifically regarding presence. A previously explored potential solution relates to the use of peripheral visual cues.

2.4.2 Peripheral Visual Cues

In an attempt to mitigate some of the shortcomings noted above from central visual cues, a different kind of attention guidance technique was explored, namely peripheral visual cues. Contrary to central visual cues, peripheral visual cues are hypothesized as ones that invoke the reflexive or involuntary attention of the user [40]. These can range from simple brightness changes at the edge of a user's screen, to complex dynamic animations outside the user's central screen.

Some studies also conclude that the use of peripheral visual cues may actually serve as a mitigator for VR motion sickness, such as the 2022 research made by Kim et al. [22].

Figure 2.3: Example of peripheral visual cues used to mitigate VR motion sickness [22]

In this experiment, peripheral visual cues were implemented as 200 blue light spheres, positioned on a virtual sphere around the participant. This structure remained stationary in the virtual environment, creating the perception of rotation when the vehicle moved. When exposed to peripheral visual cues during vehicle motion, the effect of motion sickness was indeed reduced, which objectively improves VR user experience [22]. Additionally, another paper (Stratmann et al. 2018), also assessed different implementations of peripheral visual cues using light actuators on the edge of modified safety glasses and vibrotactile displays, worn on the user's upper arms [45].

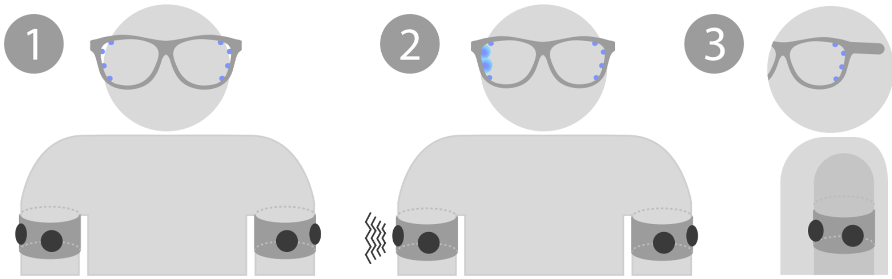

Figure 2.4: Example of peripheral visual cues in the form of light actuators. [45]

A noteworthy finding was the fact that participants experienced the highest amount of workload on tasks when no helping cues were present, which directly shows the use of these cues can actually reduce the perceived workload felt by participants. The research paper also looked into a subjective measure of annoyance, and concluded that none of the peripheral cue methods were considered annoying. This vastly contrasts to reports on central cues from other research papers previously mentioned, where central visual cues had significant negative impact in this regard.

It is also worth noting that there are significantly less studies exploring the positive and negative effects of peripheral visual cues on task performance, perceived user workload and presence, when compared to central visual cues. This, alongside some contrasting results in previously mentioned researches, reveals an opportunity for further exploration on the subject.

2.4.3 Multimodal Approaches

Finally, we can also consider multimodal cue approaches. These can include combination of both visual and non-visual cues, such as auditory or even vibrotactile cues, for attention guidance in IVEs.

The use of multiple attention guidance cues has previously shown some potential, as demonstrated by the recently published 2024 research paper on the use of auditory, visual and combined auditory-visual cues for posture guidance methods within a virtual environment [20]. Ji et al. concluded that although "all three guidance conditions significantly improved users' ergonomic posture maintenance compared with the baseline condition [...], the combined auditory-visual guidance is the most effective and preferred method." [20], proving the beneficial use-cases for multimodal approaches for attention guidance in certain scenarios. These findings are somewhat supported by Reyes and Alles's 2021 research paper [37], where their first hypothesis, established as the use of "both visual and auditive cues leads to better guiding performance, than using visual-only cues", was partially confirmed. As explained further down in this section, the partial confirmation occurred because the multimodal benefit was only observed when a margin parameter (a threshold value that prevented constant switching between guidance devices to avoid volatility) was present, while performance in mixed and visual-only conditions was comparable when no margin was applied. The authors attributed this effect to the possibility that auditive cues could be providing better guidance when participants were guided towards inaccurate cues.

It is important however to always take into account the context, methodology and limitations of the research at hand. This becomes especially important when regarding what the participant's attention was being guided to. The purpose of Ji et al.'s [20] investigation revolved around providing "real-time ergonomic posture guidance methods in a virtual office environment" [20], which vastly differs from other attention guidance tasks analysed previously in this report. An example of these other attention guidance tasks includes the Stratmann et al. study, where participants stood in the centre of a circle surrounded by 12 pillars with LEDs on them, and had to target specific LEDs positioned at various angles surrounding them, requiring full 360° spatial awareness [45]. As briefly touched on above, Reyes and Alles's [37] conclusions only found benefit in the use of multi-modal approaches when a margin was present. The absence of this margin showcased no significant advantages to the use of both visual and auditory cues, instead of visual-only cues. HiveFive360, an extension of HiveFive, aimed to address information outside the participant's FOV [21]. HiveFive360's experimentations supported some of the ideas discussed above, with results indicating that HiveFive360 achieved significantly lower completion times when compared to FlyingARrow [16] (a multimodal approach which combines visual and auditory cues for out-of-view attention guidance, shown in Figure 2.5).

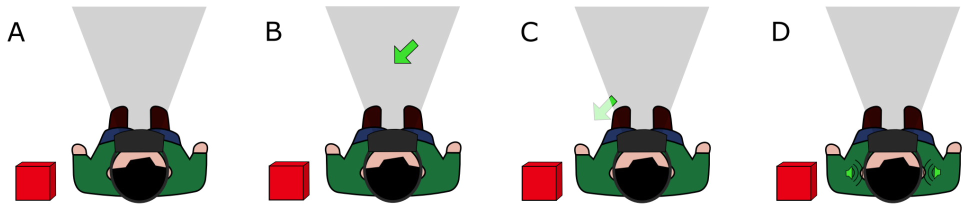

Figure 2.5: Multimodal approach - FlyingARrow. [16]

Vibrotactile cues have also been explored in the 2018 research paper by Stratmann et al. [45], together with the peripheral light actuators analysed previously in this review. These tactile cues, as seen in Figure 2.4, lead to a shorter total response time when compared to the visual cues, described by the authors as the time from when the cue was triggered, to the time the target LED was acquired. These results support the idea that tactile actuators are superior to peripheral visual cues for the acquisition of targets outside the user's direct FOV.

Based on the above findings, the importance of optimizing attention guidance techniques in VR and IVEs is evident. Capturing and managing a user's attention can have numerous benefits and effects on the target if implemented correctly, but can simultaneously introduce negative drawbacks in the process.

2.5 Research Relevance

After considering and analysing the existing forms of central, peripheral, and multimodal cue approaches, we infer they all have their own benefits and limitations. Generally speaking, central visual cues excel in maximizing task performance metrics within the studied experiments, but can many times feel overwhelming for the user, or sacrifice on the user's perceived cognitive workload, and sense of presence. Conversely, peripheral cues are usually better at preserving the sense of presence but lack the effectiveness of central or multimodal approaches for task performance optimization tasks. That being said, not all the published research supports the idea that one technique is overall better than the other, suggesting further investigation that directly compares the effects of central visual cues to peripheral visual cues, as attention guidance techniques in VR, could prove elucidating.

Given the growing application and importance of attention guidance within VR in a multitude of domains previously mentioned, additional investigation seems to be warranted. Specifically, research on the effects of peripheral visual cues as an attention guidance technique in VR could be valuable, given the suggested advantage of these types of visual cues in tasks where presence preservation and / or reduced cognitive workload is of increased importance. This investigation could ultimately help in continued development of an optimal attention guidance method that combines the advantages and mitigates the limitations of the techniques aforementioned in this report.

While existing research has explored peripheral visual cues in some contexts, significant gaps remain in understanding their effectiveness specifically within immersive virtual environments. Previous studies have not directly studied the attention guidance effectiveness and presence preservation capabilities, of central and peripheral visual cues, when compared to one another. The proposed study directly compares these two visual cue categories and their effectiveness on drawing user attention, in the context of VR and IVEs. Moreover, the study also aims to investigate the impact on users' sense of presence and overall workload, when peripheral visual cues are utilized for attention guidance, in the context of VR and IVEs. Finally, the study would ideally result in the development of a peripheral visual cue technique that effectively improves user attention in IVEs, without significantly reducing the sense of presence, nor increasing perceived cognitive workload.

Chapter 3

User Study

The evaluation of the four visual cues required the development of a comprehensive user study, able to assess each cue's effectiveness in directing user attention within IVEs. The employed experimental methodology details are reviewed below, including the development of a specialized VR prototype, the experimental procedure, and all data collection mechanisms implemented to gather both objective and subjective data.

3.1 Prototype

A VR system where participants are placed in different three-dimensional scenarios was developed, and their responses to various visual stimuli was evaluated. The implemented solution helped gather valuable information and encompassed the creation of a controlled Immersive Virtual Environment (IVE), the development of two central and two peripheral visual cues, the integration of data collection mechanisms, namely questionnaires within the VR experience, and automatically collected metrics.

3.1.1 Development Tools and Assets

The VR experience system was created in the Unity Version 6 (6000.0.29f1 LTS) platform, leveraging the natively integrated OpenXR standard to ensure compatibility across different VR headsets. The system was developed and optimized with the HTC Vive Pro 2 virtual reality head mounted display (HMD) in mind, as this would be the hardware used for both pilot, and user tests. The HTC Vive Pro 2 was the selected headset due to its high resolution (2448 x 2448 pixels per eye), fast refresh rate (120hz) and wide field of view (120 degrees) [19], which are all important factors for an experiment where presence and performance are relevant. Furthermore, the laboratory where tests were carried out was equipped with a full 360° tracking setup with 4 sensors, and on a high-performance Windows PC equipped with an NVIDIA RTX 4090 graphics card, an Intel i9-I13900KF processor and 32GB of RAM. This configuration ensured consistent performance and accurate head tracking, mitigating the appearance of any inaccurate variables that could negatively impact reaction times or workload metrics. Keeping the system optimized also decreased performance-related issues, such as latency and "jitter", consequently reducing the chances of VR-induced motion sickness [7].

While the OpenXR package provided the core VR functionality within the application, additional implementations were required to properly integrate with the HTC Vive Pro 2 controller models, given Open XR only provided generic controller models. As such, the HTC Vive controller models were extracted from the "SteamVR Plugin" [49] Unity Package and implemented into the main application.

The development of the experimental framework relied on a combination of Unity's natively integrated tools, third-party asset packages, and custom implementations to create a consistent and controlled testing environment. Unity also allowed for automatic data and metric collection mechanisms to be natively implemented, which will be critical for the experimental design as explained in the following section 3.2 - Procedure.

3.1.2 Environment and Objects

The ideal virtual environment for this experiment needed to be visually engaging yet still computationally efficient, to maintain optimal performance in this VR application. As such, the virtual environment surrounding the participant was constructed using the POLYGON - Sampler Pack by Synty Studios [46], a low-polygon asset collection that provided pre-made backdrops, including the one used in this experiment, which was an urban city environment. Despite not being dedicated to VR applications, this asset pack's low-polygon nature ensured high performance, suitable for resource intense applications, as desired. The city backdrop environment is shown on Figure 3.1.

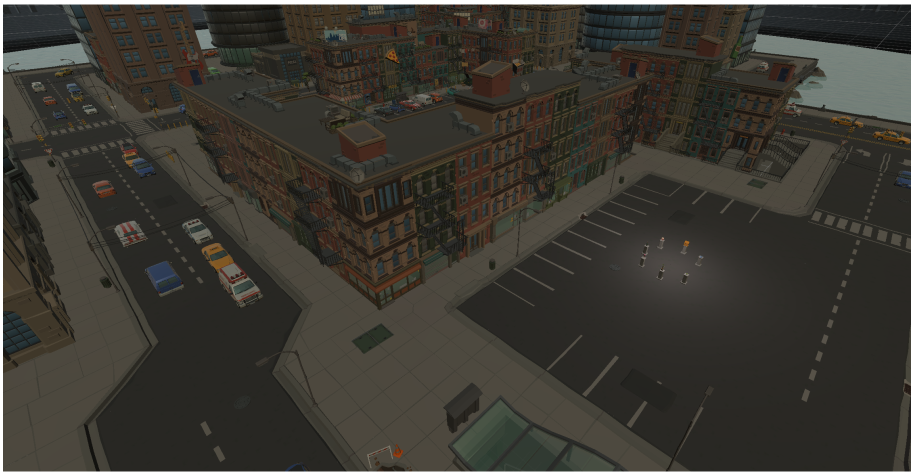

Figure 3.1: Figure showing the city backdrop virtual environment

To enhance the surrounding environment, a continuous city background soundscape was implemented, that played throughout the entirety of the experiment [26]. This ambient audio track was introduced as an attempt to reduce real-life noises breaking the sense of presence, and was kept consistent in order to avoid introducing any auditory distractions that could influence attention or presence metrics.

As previously mentioned, a total of seven objects were implemented into the scene, each on top of a pillar, and served as the target for where a participant's attention would be guided towards. All target objects, and the pillar where they were resting on top of, were also extracted from the POLYGON - Sampler Pack by Synty Studios [46] asset pack to ensure consistency in the surrounding environment. Specifically, the seven target objects used from this asset pack were:

- Tennis Ball
- House Plant
- Ice Cream Cone
- Wine Bottle
- Popcorn Bag
- Wooden Box
- Miniature Car

These objects were chosen based on their distinct visual characteristics, ensuring participants could easily differentiate between each target, and still maintain the visual consistency with the surrounding city environment. Figure 3.2 shows an example of some of the target objects on scene:

Figure 3.2: Figure showing three examples of the target object visuals

Positioning was also carefully considered: All target objects were positioned at equal distances from the participant's position, forming a circular arrangement.

Specifically, these target objects were placed at specific locations around the participant:

- Two objects were positioned at 45º from the starting position
- Two objects were positioned at 90º from the starting position
- Two objects were positioned at 135º from the starting position
- One object was positioned at 180º from the starting position

This angular distribution was specifically chosen in order to evaluate how the different visual cues would perform when directing attention to targets that varied in distances from the initial forward-facing orientation, called "starting position". The positioning can be seen on Figure 3.3 below.

Figure 3.3: Figure showing the VR experience target object positioning

As explained in further detail later in section 3.2, participants would begin each search task by first looking straight ahead (starting position). This target object arrangement therefore allowed for comprehensive testing of cue effectiveness across a range of close to far away target objects. Objects positioned at smaller angles (45º) required minimal head movement to reach and locate, while those at larger angles (135º and 180º) demanded significantly more orientation change effort. This methodology aimed to provide a thorough assessment of each cue's guidance capabilities.

Finally, it is worth mentioning that even though the scene itself was large, the VR experiment area, where participants would actually carry out tasks, was strategically positioned in the centre of an open-air parking lot, as seen on Figure 3.3. This deliberate placement eliminated close-proximity visual distractions that could interfere with the cue evaluation process. Furthermore, the parking lot provided a neutral and flat ground where participants could focus on the surrounding target objects and visual cues, without being influenced by nearby architectural elements or other environmental features that could naturally draw undesired amounts of attention.

3.1.3 Visual Cues

The experimental design incorporated two central visual cues and two peripheral visual cues, to evaluate their effectiveness in directing participant attention. The four visual cues implemented in this experiment, showcased in Figure 3.4, were:

- Central Cue 1 - Floating Text
- Central Cue 2 - Floating Arrow
- Peripheral Cue 1 - Edge Lighting
- Peripheral Cue 2 - Swarm

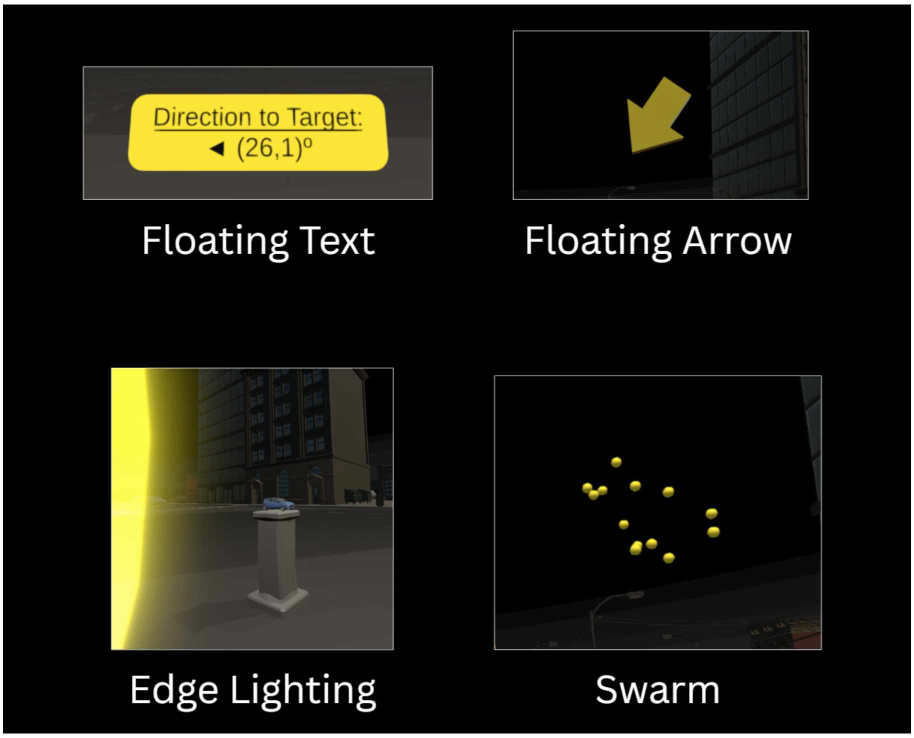

Figure 3.4: Figure showing the four visual cues used

Each cue provided visual indication of a horizontal direction suggestion, either left or right, depending on the shortest path towards the current target object from where the participant was looking at.

All of the cues used assets from Unity's default library to ensure consistency in the cues being showcased (sphere, cylinder and cube primitives were combined), and maintained a consistent yellow colour scheme to ensure visual uniformity across conditions.

3.1.3.1 Central Cue 1 - Floating Text

The first central cue consisted of a floating text UI element positioned at the horizontal centre of the participant's field of view. This text-based attention guidance cue displayed the message "Direction to Target:" followed by the precise angular measurement to the target object, to the nearest decimal place. When the target was positioned 15° or more of the participant's gaze orientation, a directional arrow character appeared alongside the angle measurement, indicating whether the participant should turn left or right towards the shortest path to the target. The 15° value was selected as an optimal balance point that provided meaningful feedback that the target object was close, without being too sensitive. Values below 15º would offer minimal practical benefit, as the target was already too close and participants might not have time to react to the dynamic nature of the cue. On the other hand, values that approached the 22.5° mark (half of the 45° object spacing), would trigger this too soon, and could mislead participants to the incorrect cue.

The text element maintained a fixed distance and position relative to the participant's camera view, ensuring consistent central visibility while the cue was active.

The Floating Text cue was the only one that also made use of the OpenXR UI assets, in a similar manner to other elements used in the application's User Interface (UI), mentioned in the upcoming subsection 3.1.4.

3.1.3.2 Central Cue 2 - Floating Arrow

The second central cue featured a 3D arrow, also positioned at the horizontal centre of the screen. This arrow continuously pointed toward the shortest path to the target object, providing intuitive directional guidance for the participant. As the participant's gaze approached the target location, the arrow exhibited two distinct dynamic changes: it gradually decreased in size (until a minimum value was reached of approx. 40% of the original size), and also began tilting downward toward the target object, in an exponentially faster manner. At the point where the arrow was positioned directly above the target, it pointed straight down and clearly indicated the target object. As with the Floating Text cue, the floating arrow maintained a consistent spatial location referent to the participant's view.

3.1.3.3 Peripheral Cue 1 - Edge Lighting

The first peripheral cue implemented was named "Edge Lighting", and was developed using large, thin spheres positioned at the horizontal edges of the participant's field of view. At any given moment, only one edge would illuminate, namely, the side corresponding to the shortest path to the target object. As the participant's orientation moved closer to the target, the light intensity gradually diminished until it completely disappeared once the participant was directly facing the target object. Moreover, a bloom post-processing effect was applied to this cue. This effect was developed using elements available in the Unity 6 native effects library, and aimed to enhance its visual impact by creating a more pronounced indication. The effect also attempted to embed this cue in the VR environment in a more natural manner. Finally, this cue was inspired by the 2018 paper "Exploring Vibrotactile and Peripheral Cues for Spatial Attention Guidance" [45], where light actuators were used at the periphery of users' vision to guide attention.

3.1.3.4 Peripheral Cue 2 - Swarm

The second peripheral cue developed was based on the original HiveFive360 [21] implementation, and features a swarm of small spheres that closely replicated the original study's visuals and behaviour, including a yellow colour scheme, particle size, movement speed and direction, and swarm density. The spheres exhibited pseudo-random hovering behaviour within a defined radius from the swarm's centre point. This peripheral visual cue was positioned at either the left or right horizontal edge of the screen, depending on the shortest path direction to the target object. Additionally, and similarly to how the original HiveFive360 [21] technique was designed, the swarm followed the participant's head movements until the target object came within a minimum distance of the participant's gaze, at which point the swarm transitioned to hovering directly above the target object. In this implementation, that critical angle was 30°. This 30° value followed a similar rationale to the 15° value in the "Central Cue 1 - Floating Text" explained above (3.1.3.1), with one key difference: Since the dynamic aspect of this cue involved the swarm hovering over the exact location of the target object, there was no risk of confusion between what the target object was, and hence the 22.5° value (half of the 45° object spacing) was not a limiting factor for this cue. Values over 30° were too close to the edge of the participant's FOV, and could have resulted in missing out on the dynamic aspect of this cue.

Finally, it is also worth noting that most of the aforementioned cues went through multiple design iterations and changes. For instance, both central cues originally had a dark blue background. This was however not ideal, as it would be significantly different from other cues, such as Peripheral Cue 2's yellow colour that stemmed from the original HiveFive360 implementation [21]. This could introduce an unwanted visual variable, and therefore all cues were given the same exact same yellow colour. Figure 3.4 shows the final visual of each of the four cues, and how they appeared in the VR experience. Other changes mainly included tweaking threshold values for each cue, such as the Floating Text cue 15° value, or the Floating Arrow min and max size.

3.1.4 Interaction Techniques

The majority of UI elements, including the initial tutorial screens, on-screen messages / prompts and general interface components, were implemented using elements from the OpenXR Unity Package's built-in UI system. This approach ensured full compatibility in a VR environment, and optimized for speed and efficiency of user navigation. Figure 3.5 shows what the UI looked like for the VR experience tutorial.

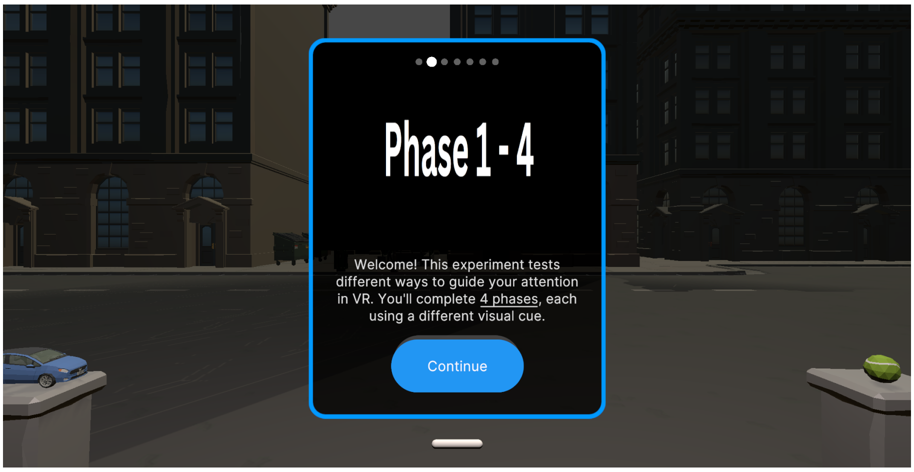

Figure 3.5: Figure showing the VR experience UI used - Tutorial Screen

For the VR experience questionnaires, namely the IGROUP Presence Questionnaire (IPQ) and NASA Task Load Index (NASA-TLX) Questionnaire, a dedicated external package was used called The Virtual Reality Questionnaire Toolkit [14], which had pre-build questionnaires and suitable answer input techniques adapted for VR and for the questionaries intended to ask. Figure 3.6 shows what these questionnaires looked like within the VR experience:

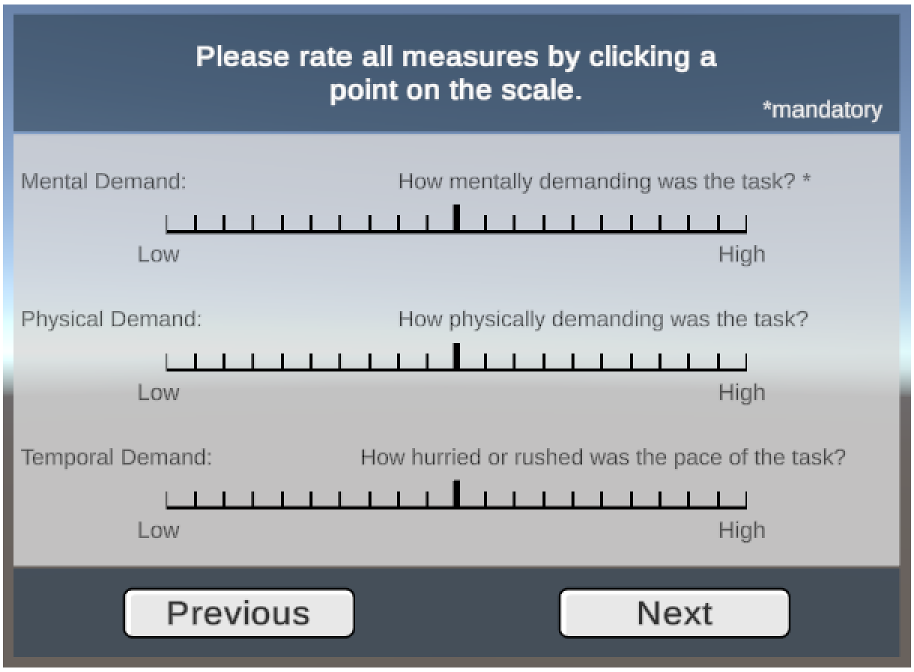

Figure 3.6: Figure showing the VR experience UI used - Questionnaire

All interactions the participant had with the application including UI interaction, questionnaire answering, and target object selection, were all performed using a single button at the back of the VR remote controller, referred to as the "main trigger" button.

Furthermore, the implementation of accurate gaze detection was critical for this experiment. To achieve this, a custom "Gaze Handler" script was developed that utilized Unity's native ray-casting system to determine the participant's gaze direction at all times, and accurately check where the participant was looking at within the scene.

The gaze detection system employed multiple ray-casts, projected from the player's main camera object, and encompassed a 30° cone in a forward direction. This angle was chosen to account for natural eye and head movement variations, while maintaining sufficient precision for accurate gaze direction identification. The ray-casts continuously updated, enabling real-time detection of gazed-upon objects within the virtual environment. This gaze detection system served two primary functions within the experimental framework:

Target Object Selection and Selection Feedback

The primary use case of the gaze handler was to determine which target object the participant was currently observing. This gaze-based selection served as the primary success condition for object identification, allowing the application to accurately check if the target acquisition attempt was valid.

Additionally, when the ray-casts intersected with a target object that was within the 30° cone, the system would activate a white highlight around the object, providing selection feedback and confirmation to the participant on which target they were currently gazing at. Confirming the target object selected was done using the main trigger button on the VR remote control. Figure 3.7 shows the difference between a target object with and without this selection feedback highlight effect.

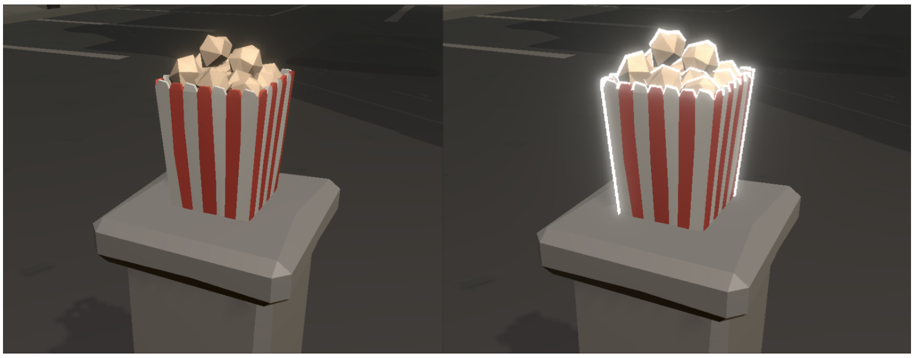

Figure 3.7: Figure showing a target object before (left) and after (right) applying the highlight effect.

Starting Position Verification

The gaze handler also monitored whether participants were looking at the designated forward-facing starting position at the beginning of each round. As explained further in this document, this functionality was essential for the experiment's core functionality, as it ensured all participants began each round from the same starting orientation (referred to as the starting position).

3.1.5 Experiment Manager

The experiment was developed around a robust state management system, designed to control the flow and functionality of the whole VR experiment. The experiment operated through multiple distinct states, with only one state active at any given time. This state-based mechanism enabled precise control over which functionalities were available during different parts of the experiment, ensuring that appropriate user interfaces, interaction mechanisms, and experimental features were activated only when required and desired. Figure 3.8 showcases how the VR experience procedure was structured, and the different states implemented:

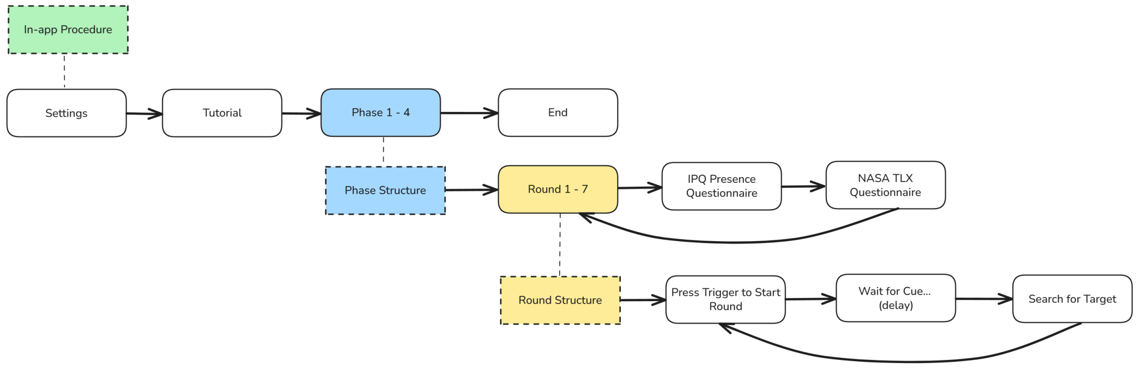

Figure 3.8: Figure showing the VR experience state-based mechanism structure

3.1.5.1 Phases and Rounds

As shown from Figure 3.8, the experiment was organized into a hierarchical structure consisting of **phases** and **rounds**. Each **phase** corresponded to the testing of one specific visual cue, meaning each participant would encounter a total of four phases. Moreover, each of the seven objects served as the target exactly once per phase, meaning each phase contained exactly seven **rounds**. In each round, participants searched for a single target object.

To ensure experimental rigour and in order to avoid introducing bias effects, the sequence of target objects within each phase was pseudo-randomized. The randomization algorithm generated a unique seven item list, with each item being a target object. This ensuring that every target object was selected exactly once while adhering to a single specific constraint: no more than two consecutive target objects could be adjacent in the angular arrangement. This constraint prevented sequences such as targets 2-3-4, 6-5-4 or even 6-7-1 (considering target #1 follows target #7 in the circular arrangement). This constraint was implemented since consecutive target object selection could potentially create predictable patterns or bias participant expectations, which could significantly alter participant performance.

Finally, the order in which phases occurred, or in other words the order of the four visual cues, was also configurable for each participant, which was necessary for the experimental design, as explained in the following section 3.2 - Procedure.

3.2 Procedure

To address the research questions and hypothesis, a user study was performed with the prototype described in the previous section 3.1. In order to provide a standardized and controlled experience for all participants, a structured experiment procedure was carried out equally with all participants. Specifically, the procedure followed a systematic progression from initial briefing, through the VR experience itself and data logging followed by data collection, ensuring consistent oversight across all experimental phases and sessions. Recruited participants were contacted via email, phone number, or directly contacted.

3.2.1 Pre-Experiment Procedure

The initial phase of the experimental session focused on preparing participants and configuring the system for optimal performance, to ensure ideal conditions for data collection. This preparatory stage encompassed both participant orientation and technical setup procedures.

3.2.1.1 Setup and Pre-Experiment Questionnaires

Upon arrival, participants received a contextual overview of the research project and its objectives, and were asked to complete a pre-test questionnaire and consent form.

Demographic and Baseline Questionnaire

Participants then filled out the "Demographic and Baseline Questionnaire" A.1, which was carried out on a secondary computer and outside the VR environment via Google Forms [15]. This questionnaire collected essential participant characteristics including age, gender, any visual conditions (and respective correction done to said condition), and details regarding previous VR experience. It also included the consent form for the experiment. The collected information helped analyse how individual differences might influence cue effectiveness and provided necessary context for interpreting experimental results. The full Demographic and Baseline Questionnaire can be found in Appendix A.1

Experiment and Test Version Setup

While participants completed this questionnaire, the test supervisor prepared the VR experimental environment. This setup process included system initialization, headset preparation, and calibration of the starting position within the virtual environment. A critical component of this preparation phase was the selection of the appropriate test version:

The experimental design incorporated test versions to counterbalance the order in which visual cues were presented to participants. Each test version specified a unique sequence for cue presentation, ensuring potential learning effects and any adaptation to the VR environment would not systematically favour or disadvantage any particular cue type. Given a total of four visual cues were tested, the number of possible combinations was of four factorial (4!), or twenty-four. The order in which cues appeared based on their test version is shown in the table 3.1:

Version	Conditions			
Version #1	CC1	CC2	PC1	PC2
Version #2	CC1	CC2	PC2	PC1
Version #3	CC1	PC1	CC2	PC2
Version #4	CC1	PC1	PC2	CC2
Version #5	CC1	PC2	CC2	PC1
Version #6	CC1	PC2	PC1	CC2
Version #7	CC2	CC1	PC1	PC2
Version #8	CC2	CC1	PC2	PC1
Version #9	CC2	PC1	CC1	PC2
Version #10	CC2	PC1	PC2	CC1
Version #11	CC2	PC2	CC1	PC1
Version #12	CC2	PC2	PC1	CC1
Version #13	PC1	CC1	CC2	PC2
Version #14	PC1	CC1	PC2	CC2
Version #15	PC1	CC2	CC1	PC2
Version #16	PC1	CC2	PC2	CC1
Version #17	PC1	PC2	CC1	CC2
Version #18	PC1	PC2	CC2	CC1
Version #19	PC2	CC1	CC2	PC1
Version #20	PC2	CC1	PC1	CC2
Version #21	PC2	CC2	CC1	PC1
Version #22	PC2	CC2	PC1	CC1
Version #23	PC2	PC1	CC1	CC2
Version #24	PC2	PC1	CC2	CC1

Table 3.1: Table showing Central Cue (CC) and Peripheral Cue (PC) test order, based on test version

This approach was essential for isolating the real effectiveness of each visual cue being tested, from external factors such as participant familiarity with the virtual environment, or accumulated experience with the tasks at hand. By systematically varying the order in which cues were tested on participants, this decision ensured any observed differences in cue performance metrics could be attributed to the inherent characteristics of the cues themselves, and not to their position in the experimental sequence. Moreover, the test version was deliberately input at the start of every participant test in a mandatory manner, to ensure participants were performing the correct test version.

Each participant received an unique test version, from 1 to 24, which consequently ensured proper counterbalancing of cue presentation orders, as outlined in the experimental design.

3.2.1.2 Participant Briefing

After completing the initial questionnaire, participants received a comprehensive briefing about the upcoming experimental procedure. This detailed explanation covered the virtual environment they would encounter, including the urban city backdrop and surrounding target objects.

The concept of the experiment "phases" and "rounds", showcased in Figure 3.8 was explained, with participants learning that once in the VR experiment, they would complete a total of four distinct "phases". Participants were also told that these four phases would each contain multiple "rounds" of target identification tasks. The objective conveyed to participants was to successfully identify and select the target object in each round.

This briefing was in-depth, but designed to avoid revealing specific details that might influence participant behaviour or expectations.

Finally, prior to beginning the VR experience, participants received important health and safety disclaimers regarding the possibility of motion sickness and were made aware of some comfort considerations. They were explicitly informed that they could request to stop the experiment at any desired moment, if they experienced discomfort. Additionally, participants were advised that they could ask questions during the experiment if they felt stuck or heavily confused, though encouraged to minimize these interruptions to maintain experimental consistency and reduced exterior influence.

3.2.2 VR Experience Procedure

Upon entering the virtual reality environment, participants were immersed in the urban backdrop with ambient city audio providing environmental context, and were ready to interact with the developed application.

3.2.2.1 Calibration, Acclimatization and Tutorial

Before starting the first of the four phases, the initial moments were dedicated to technical re-calibration of certain user-specific parameters. This included height adjustment to ensure correct perspective, and virtual experimentation area re-centring with the real life available space. Furthermore, the participant was also encouraged to take this time to get used to the environment, and simply look around. This was especially significant for participants with little to no previous VR experience, as the sensation could be somewhat overwhelming at first.

Once participants were ready, they could start interacting with the tutorial, which reinforced the briefing information previously given through visual demonstration. By making use of images and interactive elements to clarify key concepts and procedures, this tutorial ensured participants fully understood the experimental tasks before beginning data collection. After finishing the tutorial content, participants could choose to review it again, or proceed directly to the experimental phases.

3.2.2.2 Round-by-Round Procedure

The VR experiment followed a standard structure to ensure consistent timing, cue presentation, and participant interaction across all conditions. Each round followed an identical set of search tasks to maintain experimental validity and comprehensibility, while capturing precise performance metrics in the background.

Timing and Cue Presentation

Each round began with participants facing towards the forward-facing starting position. A UI element displayed "Press the Trigger to Start timer", prompting participant interaction to begin the round using the VR remote's main trigger button. Upon beginning the round, the message changed to "Wait for Cue..." indicating that the visual guidance system was moments from being active and visible. Figure 3.9 showcases the three steps involved in the start procedure of each round.

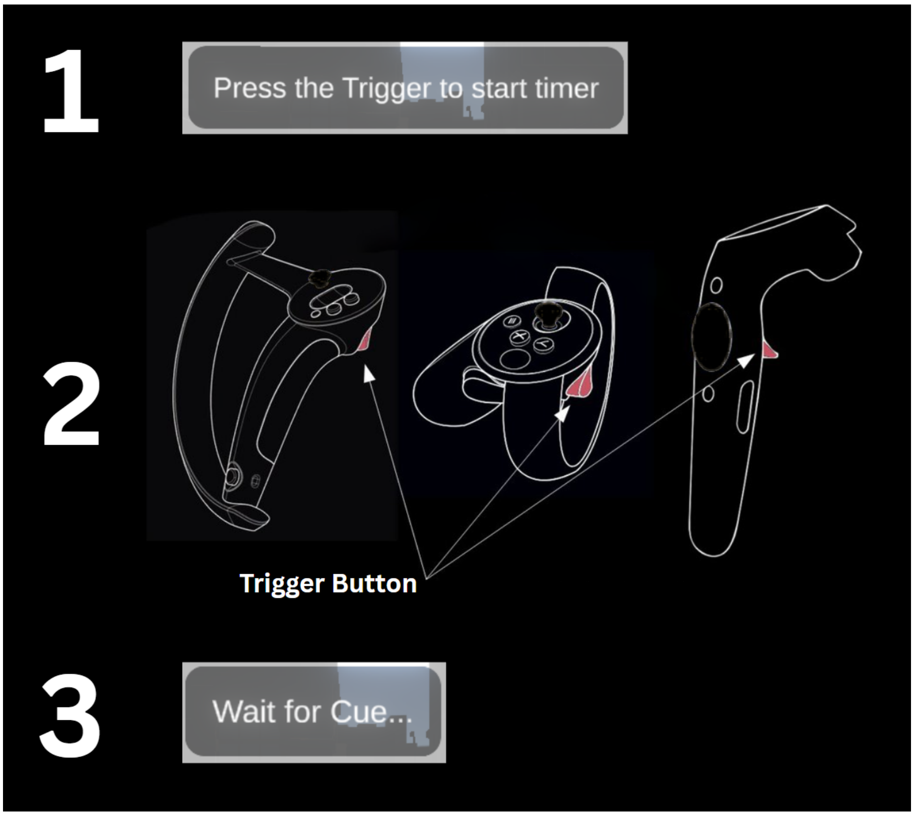

Figure 3.9: Figure showing the round start procedure

A randomized delay interval between 2 and 10 seconds preceded cue activation, preventing participants from reacting based on timing expectations rather than visual cue acknowledgement. To enforce this, if participants looked away from the starting position during this delay period, the timer would reset and a "Please look towards the starting position" message would appear, forcing participants to reorient towards the starting position before resetting the visual cue timer and proceeding.

Upon successful completion of the delay interval, the designated visual cue appeared according to the predetermined test version sequence. At this moment, both reaction time and round time measurements began. Furthermore, the reaction time timer stopped when participants first moved their gaze away from the starting position, capturing their initial response to the visual cue.

Target Selection Process

Participants indicated target selection intent by pressing the VR controller main trigger button while simultaneously gazing at their chosen object, highlighted by the white border shown on Figure 3.7. Incorrect selections triggered an audio feedback sound and incremented the error counter in the backend, but still allowed participants to continue attempting target identification within that round. Each round continued until either correct target selection occurred, or the maximum time limit of 60 seconds fully elapsed.

Round Completion and Transition

Upon successful target identification or timeout, the round time measurement concluded and data logging occurred. Data logging occurred deliberately after each round, ensuring minimal data loss in the rare event a technical issue halted the experimentation process. After the round ended, the system then displayed the "Please look towards the starting position" message, initiating the transition to the subsequent round.

This process repeated for all seven target objects within each phase, resulting in a total of 7 rounds occurring within each phase. As previously mentioned, target object selection order followed a pre-generated pseudo-random sequence that prevented three or more consecutive adjacent targets from being selected as target objects.

3.2.2.3 Phase Transitions and Questionnaires

Following completion of all seven rounds within a phase, participants were presented with the integrated questionnaire UI system, which consisted of:

IGROUP Presence Questionnaire

A scale for measuring the sense of presence experienced in a virtual environment (VE). It consists of 14 questions designed to assess the participant's sense of presence and immersion within the virtual environment. This questionnaire helped provide quantitative measures of spatial presence, involvement, and experienced realism felt by each participant [14].

NASA Task Load Index

A 6 question questionnaire that helped evaluate perceived workload across multiple dimensions, namely mental, physical and temporal demand, as well as perceived performance, effort and frustration. This assessment captured the cognitive and physical effort perceived by participants [32],

[17].

Both of these questionnaires were presented within the VR environment to maintain immersion and context. After questionnaire submission, the system automatically transitioned to the next experimental phase, introducing the next visual cue type according to the participant's assigned test version, as shown on Table 3.1. This process repeated until all four phases were completed, and the experiment was concluded.

3.2.3 Experiment Conclusion

Upon completing the final phase and associated questionnaires, the experiment concluded with a display of the participant's test version number for verification purposes. Participants then removed the VR headset and completed the final "Cue Preference Ranking Questionnaire" A.2 on a secondary computer, providing comparative evaluations of the different visual cues they had experienced. Cues were ranked using a likert scale, on six distinct characteristics:

1. Rank the four cues from most **effective** (#1) to least effective (#4) at guiding your attention to target objects.
2. Rank the four cues from most **natural/well-embedded** in the environment.
3. Rank the four cues from least **distracting** (#1) to most distracting (#4).
4. Rank the four cues from most **comfortable** to use (#1) to least comfortable (#4).
5. Rank the four cues from least **disruptive** to your sense of presence (#1) to most disruptive (#4).
6. Rank the four cues based on your **overall preference** from most preferred (#1) to least preferred (#4).

This final Cue Preference Ranking Questionnaire helped collect subjective participant evaluations across multiple dimensions, and also gave participants the opportunity to share any written comments about the experiment as a whole, or / and about any of the cues tested. The full Cue Preference Ranking Questionnaire can be found in Appendix A.2.

This systematic procedure ensured consistent data collection while maintaining a high level of participant comfort and engagement throughout the entirety of the experimental session.

Chapter 4

Results and Discussion

The comprehensive analysis of data collected from the total of 24 participants evaluates four distinct visual cue types in an immersive virtual environment, as shown in Table 4.1:

ID	Cue	Alias
CC1	Central Cue 1	Floating Text
CC2	Central Cue 2	Floating Arrow
PC1	Peripheral Cue 1	Edge Lighting
PC2	Peripheral Cue 2	Swarm

Table 4.1: Table showing the four cues tested, and their respective IDs and aliases

The investigation examines how peripheral visual cues affect user attention in Immersive Virtual Environments (IVEs) compared to central cues. The study also evaluates their impact on presence and workload, testing whether these cues can effectively guide attention while also maintaining a quality sense of immersion.

The experimental data encompasses both objective performance metrics and subjective user assessments. Performance measures include round completion times, cue reaction times, and error rates across all cue conditions, which together provide quantitative insights into attention and task efficiency. Subjective measures comprise of IPQ scores across three subscales (Spatial Presence, Involvement, and Experienced Realism), NASA-TLX questionnaire for workload, and a comparison questionnaire for ranking the presented cues across a total of six dimensions: effectiveness in guiding to targets, natural embedding in the environment, comfort, distraction levels, presence disruption, and overall preference.

Repeated measures ANOVA was employed to examine differences between cue types, accounting for the within-subjects experimental design. For cue ranking comparisons (Cue Preference Ranking Questionnaire A.2), Friedman tests were utilized as a non-parametric alternative due to the ordinal nature of ranking data. Given the violation of normality assumptions across multiple measures, the analysis proceeded with appropriate statistical tests and correction, in order to provide robust empirical evidence.

4.1 Data Preparation and Statistical Approach

A series of data preparation procedures and statistical methodologies were employed to analyse the raw experimental data collected. These steps ensured data integrity was maintained, and appropriate analytical approaches were used for addressing the research questions regarding peripheral versus central visual cues in immersive virtual environments, and answering the proposed hypothesis.

4.1.1 Initial Data Preparation and Computed Variables

The experimental data was imported into SPSS version 30.0.0.0 (172) for comprehensive statistical analysis. From the raw dataset, computed variables were created directly within SPSS to facilitate analysis across the four cue conditions: Floating Text, Floating Arrow (central cues), Edge Lighting, and Swarm (peripheral cues).

For each cue condition, performance metrics were computed including mean reaction time, mean round time, and total errors across all seven rounds. Additionally, presence and workload measures were calculated as averaged scores for each cue. IPQ scores were computed on a 0-6 scale for three components: Spatial Presence, Involvement, and Experienced Realism, along with a total IPQ score representing the average across all components. The IPQ Spatial Presence component incorporated the general presence question as recommended by the Igroup website, due to its strong relationship with spatial presence [41]. NASA-TLX workload scores were computed as averages across all six dimensions, resulting in scores ranging from 1-20 for each cue condition.

Data integrity procedures included reversing specific IPQ items (Q3, Q9, Q11) and NASA TLX items (G4) that were purposely reversed in the questionnaire to verify participant attention and response consistency.

4.1.2 Outlier Detection and Removal

Outlier detection employed the Interquartile Range (IQR) box-plot method to identify regular and extreme outliers, across all analysed variables and metrics. The analysis distinguished between regular outliers (1.5 × IQR beyond quartiles) and extreme outliers (3.0 × IQR beyond quartiles), with only extreme outliers being removed to preserve data integrity, while still eliminating potentially erroneous measurements. A total of **six** extreme outliers were identified and removed from the dataset, originating from three unique participants: participant #2 (one outlier), participant #22 (two outliers), and participant #23 (three outliers). These outliers were distributed across reaction time and round time metrics for various cue conditions. It is also worth noting that an exception was made in this process, where extreme outliers in the "total errors" category were deliberately retained in the analysis, as these errors represent legitimate behaviour responses. A clear example of this occurred in the computed variable "Central Cue 2 - Total Errors", where almost all participants had a total of zero errors, resulting in an interquartile range of also zero. This meant that the three participants who made a single error would be classified as extreme outliers, which does not represent genuine measurement artifacts but rather legitimate task performance variations.

4.1.3 Normality Testing

Normality assessment utilized the Shapiro-Wilk test across all dependent variables, for each visual cue. The results revealed violations of normality assumptions, with at least one condition failing the normality test for each measured variable. Due to normality violations in the collected data, non-parametric statistical methods were applied across all analyses consistently, to maintain analytical coherence.

4.1.4 Statistical Analysis

A repeated measures ANOVA was applied to examine differences between the four cue types, appropriate for the within-subjects experimental design, where each participant experienced all four cue conditions. Post-hoc pairwise comparisons were conducted using Bonferroni correction to account for multiple comparisons and identify specific differences between individual cue pairs when significant effects and discrepancies were detected.

For cue ranking comparisons, Friedman tests were employed as a non-parametric alternative, given the ordinal nature of the ranking data. Significance testing utilized an alpha level of 0.05 for all analyses.

4.2 Results

The experimental study involved a total of 24 participants who completed the VR visual attention tasks across four different cue designs. The participant demographics encompasses a diverse range of participant age groups (15 to 75 years old, with a mean age of 34.4 years), and a balanced participant sex ratio (54.2% male and 45.8% female).

Regarding previous VR experience, most participants (45.8%) had no previous experience with VR, followed by 33.3% of participants who self classified as "beginners", 12.5% as "intermediate", and 8.3% as "advanced". No participants reported an "expert" level of VR experience. Moreover, vision conditions showed that the vast majority (70.9%) of participants had some kind of vision issue that was corrected with either glasses or contact lenses, while only 29.2% reported having no vision issues.

4.2.1 Attention and Performance Metrics

Three distinct metrics were analysed to examine differences in attention and task efficiency across all four visual cues. Table 4.2 presents the results for the mean results for **reaction time**, **round time** and **total errors**, as well as respective standard deviations. Table 4.3 presents the summary of pairwise comparison results for these same metrics, with significant results highlighted in light green.

Mean - VR Experiment Metrics			
Metric	**Cue**	**Mean**	**Std. Deviation**
Reaction Time	CC1	1.00	0.32
	CC2	0.66	0.14
	PC1	0.83	0.32
	PC2	0.67	0.15
Round Time	CC1	6.11	4.87
	CC2	2.79	1.12
	PC1	6.44	5.55
	PC2	3.26	1.77
Total Errors	CC1	0.54	0.72
	CC2	0.17	0.38
	PC1	2.00	3.44
	PC2	0.75	1.11

Table 4.2: Table showing results for the VR experiment metrics

ANOVA Tests - VR Experience Metrics			
Metric	**Cue comparison**	**Mean Dif. (A - B)**	**Sig.**
Reaction Time	CC1 vs CC2	0.33	< 0.001
	CC1 vs PC1	0.16	0.02
	CC1 vs PC2	0.33	< 0.001
	CC2 vs PC1	-0.17	0.01
	CC2 vs PC2	0.00	1.00
	PC1 vs PC2	0.16	0.11
Round Time	CC1 vs CC2	3.32	0.01
	CC1 vs PC1	-0.34	1.00
	CC1 vs PC2	2.85	0.03
	CC2 vs PC1	-3.65	0.01
	CC2 vs PC2	-0.47	1.00
	PC1 vs PC2	3.18	0.03
Total Errors	CC1 vs CC2	0.38	0.22
	CC1 vs PC1	-1.46	0.31
	CC1 vs PC2	-0.21	1.00
	CC2 vs PC1	-1.83	0.10
	CC2 vs PC2	-0.58	0.16
	PC1 vs PC2	1.25	0.37

Table 4.3: Table showing ANOVA pairwise comparisons w/ Bonferroni adjustment for VR Experience Metrics

Reaction Time

A repeated measures ANOVA revealed a significant main effect of cue type on reaction time, $F(3, 60) = 19.63$, $p < 0.001$. Reaction time showed significant differences between several different cue pairs. Central Cue 1 (Floating Text) demonstrated significantly longer reaction times when compared with all other cues:

- +0.33 seconds ($p < 0.001$) of mean difference when compared with Central Cue 2 (Floating Arrow)
- +0.16 seconds ($p = 0.020$) of mean difference when compared with Peripheral Cue 1 (Edge Lighting)
- +0.33 seconds ($p < 0.001$) of mean difference when compared with Peripheral Cue 2 (Swarm)

On the other hand, Central Cue 2 showed a somewhat significantly faster reaction times than Peripheral Cue 1 by 0.17 seconds ($p = 0.01$). Additionally, no significant differences were observed between Central Cue 2 and Peripheral Cue 2 ($p = 1.000$), neither between the two peripheral cues ($p = 0.11$).

Round Time

A repeated measures ANOVA showed a significant main effect of cue type on round time, $F(3, 63) = 9.67$, $p < 0.001$. Round time results revealed significant differences across multiple cue comparisons, too. Central Cue 1 resulted in a significantly higher round time than Central Cue 2 by 3.32 seconds ($p = 0.01$), and Peripheral Cue 2 by 2.85 seconds ($p = 0.03$). Peripheral Cue 1 also saw significantly longer round times when compared with Central Cue 2 and Peripheral Cue 2, by 3.65 seconds ($p = 0.01$) and by 3.18 seconds ($p = 0.03$), respectively. Furthermore, no significant differences were found between Central Cue 1 and Peripheral Cue 1 ($p = 1.00$), nor between Central Cue 2 and Peripheral Cue 2 ($p = 1.00$).

Total Errors

A repeated measures ANOVA revealed a significant main effect of cue type on total errors, $F(3, 69) = 4.84$, $p = 0.004$. However, post-hoc pairwise comparisons showed no statistically significant differences between any cue pairs, with all p-values exceeding 0.05. The largest mean difference was observed between Central Cue 2 and Peripheral Cue 1 (1.83 errors, $p = 0.10$), though this did not reach the threshold p-value of 0.05 to be considered of statistical significance.

4.2.2 Presence and Workload

Presence and workload were assessed using the IPQ components [14] and NASA-TLX [17], respectively. Table 4.4 summarizes the mean scores for the subjective IPQ and NASA TLX scores, along with standard deviation of each. Table 4.5 summarizes the pairwise comparisons for these subjective measures, with significant results highlighted in light green.

Mean - IPQ + NASA TLX			
Metric	**Cue**	**Mean**	**Std. Deviation**
IPQ Score - Spatial	CC1	6.19	1.55
	CC2	6.57	1.05
	PC1	6.40	1.09
	PC2	6.63	0.98
IPQ Score - Involvement	CC1	4.90	1.09
	CC2	4.86	1.16
	PC1	4.98	0.99
	PC2	5.07	1.02
IPQ Score - Experienced Realism	CC1	3.22	0.89
	CC2	3.54	0.95
	PC1	3.44	0.99
	PC2	3.64	1.20
IPQ Score - Total	CC1	3.58	0.61
	CC2	3.74	0.58
	PC1	3.70	0.61
	PC2	3.84	0.58
NASA TLX Score	CC1	4.78	3.34
	CC2	2.67	1.83
	PC1	4.76	3.15
	PC2	3.20	2.46

Table 4.4: Table showing results for IPQ and NASA TLX Scores

IPQ + NASA TLX			
Metric	**Cue comparison**	**Mean Dif. (A - B)**	**Sig.**
IPQ Score - Spatial	CC1 vs CC2	-0.38	0.38
	CC1 vs PC1	-0.21	1.00
	CC1 vs PC2	-0.44	0.46
	CC2 vs PC1	0.17	0.71
	CC2 vs PC2	-0.07	1.00
	PC1 vs PC2	-0.23	1.00
IPQ Score - Involvement	CC1 vs CC2	0.03	1.00
	CC1 vs PC1	-0.08	1.00
	CC1 vs PC2	-0.18	1.00
	CC2 vs PC1	-0.12	1.00
	CC2 vs PC2	-0.21	1.00
	PC1 vs PC2	-0.09	1.00
IPQ Score - Experienced Realism	CC1 vs CC2	-0.32	0.38
	CC1 vs PC1	-0.22	1.00
	CC1 vs PC2	-0.42	0.29
	CC2 vs PC1	0.10	1.00
	CC2 vs PC2	-0.09	1.00
	PC1 vs PC2	-0.20	1.00
IPQ Score - Total	CC1 vs CC2	-0.17	0.31
	CC1 vs PC1	-0.13	1.00
	CC1 vs PC2	-0.26	0.17
	CC2 vs PC1	0.04	1.00
	CC2 vs PC2	-0.09	1.00
	PC1 vs PC2	-0.13	0.99
NASA TLX Score	CC1 vs CC2	2.12	0.01
	CC1 vs PC1	0.03	1.00
	CC1 vs PC2	1.58	0.02
	CC2 vs PC1	-2.09	0.01
	CC2 vs PC2	-0.54	1.00
	PC1 vs PC2	1.56	0.13

Table 4.5: Table showing ANOVA pairwise comparisons w/ Bonferroni adjustment for IPQ and NASA TLX Scores

IPQ Component Scores

A repeated measures ANOVA revealed no significant main effect of cue type on IPQ Spatial Presence scores, $F(3, 69) = 2.37$, $p = 0.08$. IPQ Spatial Presence scores demonstrated no significant differences between any of the 6 cue pairs compared, with all comparisons yielding p-values of 0.38, or above. The largest mean difference was observed between Central Cue 1 and Peripheral Cue 2 (-0.44, p = 0.46), indicating a slight trend favouring Peripheral Cue 2, but not enough to be considered of statistical significance.

A repeated measures ANOVA showed no significant main effect of cue type on IPQ Involvement scores, F(3, 69) = 0.58, p = 0.633. IPQ Involvement scores similarly showed no significant differences across all pairwise comparisons, with p-values of 1.00 for all tests. Mean differences were minimal, ranging from -0.03 to -0.21.

A repeated measures ANOVA revealed no significant main effect of cue type on IPQ Experienced Realism scores, F(3, 69) = 1.67, p = 0.18. IPQ Experienced Realism scores also revealed no significant differences between the 4 visual cues, with all p-values exceeding 0.29, and also reaching 1,00 for some tests.

Finally, a repeated measures ANOVA showed no significant main effect of cue type on IPQ Total scores, F(3, 69) = 2.64, p = 0.06. IPQ Total scores also failed to achieve statistical significance in any pairwise comparison, although came closer than each individual component. The largest difference was between Central Cue 1 and Peripheral Cue 2 (-0.26, p = 0.17), suggesting a trend toward higher overall presence with Peripheral Cue 2, though once again, this remained non-significant.

NASA-TLX Total Scores

NASA-TLX Total scores were different; a repeated measures ANOVA did reveal a significant main effect of cue type on NASA-TLX Total scores, F(3, 69) = 7.93, p = 0.001. NASA-TLX Total Scores also showed significant differences across several of the cue comparisons. Central Cue 1 resulted in significantly higher workload than Central Cue 2 by 2.12 points (p = 0.01) and Peripheral Cue 2 by 1.58 points (p = 0.02). Peripheral Cue 1 also demonstrated significantly higher workload compared to Central Cue 2 by 2.090 points (p = 0.01). Finally, no significant differences were found between Central Cue 1 and Peripheral Cue 1 (p = 1.00), Central Cue 2 and Peripheral Cue 2 (p = 1.00), or Peripheral Cue 1 and Peripheral Cue 2 (p = 0.13).

4.2.3 User Preferences and Subjective Rankings

Finally, participants ranked each cue from 1 (best) to 4 (worst) across six evaluation dimensions. Lower median ranks indicate better performance or more desirable cue characteristic, in each category. Table 4.6 showcases median and Inter Quartile Range (IQR) results for all ranking categories that each cue was subjected to. Table 4.7 presents the Chi-Square (χ^2) and p-value results for all ranking categories, which was done using Friedman tests considering the ordinal nature of these data points, and with significant results highlighted in light green.

Median - Cue Ranking			
Metric	**Cue**	**Median**	**IQR**
Effectiveness	CC1	3.00	2.00
	CC2	2.00	1.00
	PC1	3.50	1.00
	PC2	2.00	1.00
Embedding	CC1	4.00	1.00
	CC2	2.00	1.00
	PC1	3.00	2.00
	PC2	1.00	1.00
Distraction	CC1	3.00	2.00
	CC2	2.00	1.50
	PC1	3.00	2.00
	PC2	1.50	2.00
Comfort	CC1	3.00	1.00
	CC2	2.00	1.50
	PC1	4.00	1.50
	PC2	1.00	1.00
Presence Impact	CC1	3.00	1.00
	CC2	2.00	1.00
	PC1	4.00	1.50
	PC2	1.00	1.00
Overall Preference	CC1	3.00	1.00
	CC2	2.00	1.00
	PC1	3.50	1.00
	PC2	1.00	1.00

Table 4.6: Table showing median and IQR results for Cue Ranking

Friedman Tests - Cue Ranking		
Metric	**Chi-Square**	**P-Value**
Effectiveness	26.60	<0.001
Embedding	22.45	<0.001
Distraction	12.15	0.01
Comfort	31.55	<0.001
Presence Impact	30.20	<0.001
Overall Preference	29.35	<0.001

Table 4.7: Table showing Friedman Chi-Square and P-Values for Cue Rankings

Effectiveness

A Friedman test revealed significant differences in effectiveness rankings across the four visual cues, $\chi^2(3) = 26.60$, $p < 0.001$. Central Cue 2 (Floating Arrow) and Peripheral Cue 2 (Swarm) were both ranked as most effective with identical median ranks of 2.00. Central Cue 1 (Floating Text) received a median rank of 3.00, while Peripheral Cue 1 (Edge Lighting) was ranked least effective with a median rank of 3.50.

Embedding

Friedman test analysis showed significant differences in how naturally embedded participants perceived each cue to be, $\chi^2(3) = 22.45$, $p < 0.001$. Peripheral Cue 2 (Swarm) was rated as most naturally embedded with a median rank of 1.00, followed by Central Cue 2 (Floating Arrow) with a median rank of 2.00. Peripheral Cue 1 (Edge Lighting) received a median rank of 3.00, while Central Cue 1 (Floating Text) was perceived as least naturally embedded with a median rank of 4.00.

Distraction

The Friedman test indicated significant differences in distraction levels between cues, $\chi^2(3) = 12.15$, $p = 0.01$. Peripheral Cue 2 (Swarm) was rated as least distracting with a median rank of 1.50, followed by Central Cue 2 (Floating Arrow) with a median rank of 2.00. Both Central Cue 1 (Floating Text) and Peripheral Cue 1 (Edge Lighting) received identical median ranks of 3.00, indicating they were perceived as equally more distracting.

Comfort

Significant differences in comfort rankings were found using the Friedman test, $\chi^2(3) = 31.55$, $p < 0.001$. Peripheral Cue 2 (Swarm) was ranked as most comfortable with a median rank of 1.00, followed by Central Cue 2 (Floating Arrow) with a median rank of 2.00. Central Cue 1 (Floating Text) received a median rank of 3.00, while Peripheral Cue 1 (Edge Lighting) was rated as least comfortable with a median rank of 4.00.

Presence Impact

The Friedman test revealed significant differences in how much each cue disrupted the sense of presence, $\chi^2(3) = 30.20$, $p < 0.001$. Peripheral Cue 2 (Swarm) was perceived as least disruptive to presence with a median rank of 1.00, followed by Central Cue 2 (Floating Arrow) with a median rank of 2.00. Central Cue 1 (Floating Text) received a median rank of 3.00, while Peripheral Cue 1 (Edge Lighting) was rated as most disruptive to presence with a median rank of 4.00.

Overall Preference

Friedman test analysis showed significant differences in overall preference rankings, $\chi^2(3)$ = 29.35, $p < 0.001$. Peripheral Cue 2 (Swarm) emerged as the most preferred cue with a median rank of 1.00, followed by Central Cue 2 (Floating Arrow) with a median rank of 2.00. Central Cue 1 (Floating Text) received a median rank of 3.00, while Peripheral Cue 1 (Edge Lighting) was ranked as least preferred with a median rank of 3.50.

4.3 Discussion

The experimental findings reveal a complex pattern of effects that provide valuable insights into the comparative effectiveness between central and peripheral visual cues, within Immersive Virtual Environments (IVEs). While overall, results demonstrate clear performance advantages for specific and individual cue designs, the cue's positioning type (central or peripheral) present a more nuanced picture that requires careful interpretation in the context of the original research questions and hypothesis. The following analysis examines these findings across attention and performance metrics, presence and workload measures, and also subjective preferences, in an attempt to understand the implications for IVE design and implementation of these attention guidance techniques.

4.3.1 Peripheral and Central Cues: Attention Effects

The analysis of attention and performance metrics provides mixed support for the hypothesis that peripheral visual cues are more effective than central cues in drawing user attention. When examining the positioning type specifically (central or peripheral), results reveal that the distinction between central and peripheral placement is less pronounced than initially anticipated, with cue design characteristics playing a more noticeable role in determining performance outcomes.

4.3.1.1 Cue Position Influence on Performance

Comparing the two central cues (CC1 - Floating Text and CC2 - Floating Arrow) against the two peripheral cues (PC1 - Edge Lighting and PC2 - Swarm), data shows that neither positioning category demonstrates consistent superiority across all three performance metrics collected. As shown in Table 4.2, for reaction time, Central Cue 1 (Floating Text) showed the longest response times (M = 1.00s), while Central Cue 2 (Floating Arrow) and Peripheral Cue 2 (Swarm) achieved some of the fastest responses (M = 0.66s and M = 0.67s, respectively). This pattern suggests that the visual design of the cue, specifically whether it uses text or arrow-based guidance, has a stronger influence on reaction speed than its spatial positioning (central or peripheral).

The round time result analysis reinforces this "cue design-over-position" effect, given that both Central Cue 1 (M = 6.11s) and Peripheral Cue 1 (M = 6.44s) required significantly longer completion times when compared to Central Cue 2 (M = 2.79s) and Peripheral Cue 2 (M = 3.26s). Furthermore, the lack of significant differences between Central Cue 1 and Peripheral Cue 1 (p = 1.000), and between Central Cue 2 and Peripheral Cue 2 (p = 1.000), also indicates that cue type / positioning alone does not substantially impact task completion efficiency. Finally, results seem to suggest that neither cue type nor design significantly impact the amount of errors done by participants.

4.3.2 Presence and Workload Implications

The analysis of presence and workload measures provides important insights into the hypothesis that "Peripheral visual cues are effective in drawing user attention in IVEs without negatively impacting workload or sense of presence". These findings demonstrate no credible evidence that visual cue positioning (central or peripheral) has an impact on presence measures, but simultaneously revealed the existence of meaningful differences in regards to cognitive workload.

4.3.2.1 IPQ Presence Components

The IPQ results demonstrate remarkably consistent presence levels across all four cue conditions, with no significant differences in Spatial Presence, Involvement, or Experienced Realism. All tests revealed non-significant results, with p-values of 0.29 or above, well above the 0.05 threshold. These findings are consistent with the hypothesis, as no evidence was found that peripheral cues (Edge Lighting and Swarm) significantly reduce the sense of presence when compared to central cues (Floating Text and Floating Arrow). The Total IPQ scores were not statistically different, with Central Cue 1 compared to Peripheral Cue 2 showing a p-value of 0.17 and a maximum IPQ Total Score difference of 0.26 points. In any case, IPQ results reveal no meaningful distinctions between any of the tested cues, suggesting the study was unable to identify differences between central and peripheral positioning techniques in terms of presence impact.

Some methodological considerations warrant acknowledgement; participant feedback occasionally indicated some uncertainty about specific IPQ questions, particularly those that regarded conceptual items such as Question 3 ("I felt like I was just perceiving pictures"). Additionally, language barriers for non-native English speakers required occasional clarification during the VR experience, when filling out questionnaires. Despite these inherent limitations, the consistent result of non-significant differences across all three presence components, and total score, provides reliable evidence that cue positioning does not substantially impact participants' sense of presence in VR.

4.3.2.2 NASA-TLX Workload

In contrast to the IPQ findings, NASA-TLX workload assessments revealed significant differences between multiple cue variations. Central Cue 1 (Floating Text) demonstrated significantly higher cognitive workload scores ($M = 4.78$) compared to Central Cue 2 ($M = 2.67$, $p = 0.01$) and Peripheral Cue 2 ($M = 3.20$, $p = 0.02$). Similarly, Peripheral Cue 1 (Edge Lighting) showed significantly higher workload scores ($M = 4.76$) compared to Floating Arrow ($p = 0.01$).

The NASA TLX workload findings reveal that the cognitive burden is once again determined by cue design characteristics, rather than solely by its positioning respective to the participant's view. Both Central Cue 1 and Peripheral Cue 1 imposed higher cognitive demands than their Peripheral Cue 2 and Central Cue 2 comparison tests, respectively.

4.3.3 Research Questions and Hypothesis Evaluation

The experimental findings provide important insights into the effectiveness of peripheral versus central visual cues in the context of Immersive Virtual Environments (IVEs). To directly address the research questions and evaluate the experimental hypothesis, developed data analysis were synthesized and linked back towards each of the investigation's research questions and hypothesis.

4.3.3.1 Research Question 1: Peripheral Visual Cues and User Attention Draw

Starting off with the first research question, RQ1 asked "How effective are peripheral visual cues in drawing attention in IVEs compared to central cues?". The performance metrics and result analysis reveal that peripheral cues do not demonstrate consistent attention advantages over central alternatives. When comparing positioning categories directly, neither peripheral cues (Edge Lighting and Swarm) nor central cues (Floating Text and Floating Arrow) showed systematic benefits regarding reaction time, round time, or error measures.

This lack of systematic benefit is showcased by the reaction time analysis, that showed Central Cue 2 (M = 0.66s) and Peripheral Cue 2 (M = 0.67s) achieved comparably fast responses, while Central Cue 1 (M = 1.00s) and Peripheral Cue 1 (M = 0.83s) both required longer processing times. Similarly, round time patterns revealed that task completion efficiency was mainly determined by cue design characteristics rather than spatial positioning on-screen, with no significant differences between Central Cue 1 and Peripheral Cue 1 ($p = 1.000$) or between Central Cue 2 and Peripheral Cue 2 ($p = 1.000$).

The subjective ranking data provides reinforcing evidence that attention-related preferences are not primarily driven by positioning of the cue being experienced. Effectiveness rankings showed that Central Cue 2 (M = 2.00) and Peripheral Cue 2 (M = 2.00) were both rated as highly effective, while Central Cue 1 (M = 3.00) and Peripheral Cue 1 (M = 3.50) received lower effectiveness scores (higher median rank). This pattern reinforces the conclusion that cue design, rather than peripheral positioning, has a higher impact on attention guidance effectiveness.

4.3.3.2 Research Question 2: Impact on Presence and Workload

Regarding the 2nd research question, RQ2 examined "How is the user's sense of presence and workload impacted by peripheral visual cues, in IVEs?". No credible evidence was found for differences in perceived presence levels when comparing peripheral with central cues, while showing variable effects on cognitive workload.

As demonstrated on Table 4.5, the IPQ presence components revealed no significant differences between peripheral and central cues across Spatial Presence, Involvement, and Experienced Realism measures. Findings suggest that the performed comparisons were unable to conclude if peripheral positioning compromises immersive experience quality, and that participants' presence levels were affected by cue placement. Furthermore, whilst peripheral cues showed somewhat higher mean IPQ Scores for each presence component, no significant differences were found in this study between the two distinct positioning methods.

Conversely, the NASA-TLX workload findings revealed there are indeed some significant differences in cognitive demands. These differences varied by specific cue implementation, rather than by positioning alone. Central Cue 1 (M = 4.78) and Peripheral Cue 1 (M = 4.76) both imposed higher workload compared to Central Cue 2 (M = 2.67) and Peripheral Cue 2 (M = 3.20), indicating that the impact depends on design characteristics rather than spatial location. The subjective ranking data further supports this conclusion, with comfort rankings showing that Central Cue 2 (M = 2.00) and Peripheral Cue 2 (M = 1.00) both received significantly higher comfort scores (lower ranking), while Central Cue 1 (M = 3.00) and Peripheral Cue 1 (M = 4.00) were rated as less comfortable.

4.3.3.3 Hypothesis Evaluation

This investigation's hypothesis stated that "Peripheral visual cues are effective in drawing user attention in IVEs without negatively impacting the sense of presence and workload, when compared to central visual cues". The experimental evidence provides partial support for this hypothesis, with important considerations that reveal the complexity of attention guidance mechanisms in IVEs.

The **presence preservation** component of the hypothesis is consistent with the IPQ findings; no credible evidence for differences in any of the analysed presence components were found, including spatial presence, involvement, and experienced realism, when comparing peripheral to central cue attention guidance techniques.

It is worth noting that these results should be interpreted considering the context of the experimental design, where task performance was prioritized over an immersive storytelling experience. The experience had participants primarily engaged in target acquisition activities, and may have limited the potential for presence disruption, regardless of cue type. An example of an environment where presence is more valuable is a narrative-driven VR experience, where environmental engagement is paramount, and hence the impact of cue positioning on presence could be more pronounced.

Furthermore, the **attention draw** component of the hypothesis is not supported by the performance data collected: peripheral visual cues did not demonstrate a consistent advantage in reaction time, round time, or error measures when compared to central cues. Collected performance metrics challenge the established assumption that peripheral cue positioning inherently provides attention guidance benefits, over central positioning. The effectiveness of visual guidance appears to be determined primarily by cue design characteristics and implementation choices, rather than spatial positioning within the user's field of view. Furthermore, the absence of significant error rate differences across all cue comparison tests further supports the idea that cue positioning does not impact task accuracy in a significant manner. These findings have important implications for understanding attention guidance mechanisms in IVEs, as they suggest users may be equally capable of processing guidance information from both central and peripheral locations, as long as cue design is appropriately designed and optimized.

Finally, the **workload** component shows mixed results: workload assessments revealed that the impact varies significantly based on specific cue implementation. The NASA-TLX findings present a complex picture, where the relationship between cue positioning and workload is heavily mediated by design implementation factors. While Peripheral Cue 2 (Swarm) achieved a lower workload than Central Cue 1 (Floating Text), Peripheral Cue 1 (Edge Lighting) on the other hand demonstrated elevated cognitive mental demands, which compared to the most demanding central cue implementation. Moreover, a well-designed peripheral cue (such as Swarm, which was based on the thoroughly tested HiveFive360 [21] implementation) can achieve cognitive efficiency comparable to optimal central alternatives, but poorly designed peripheral implementations (such as Edge Lighting) may impose elevated cognitive demands.

These findings indicate that the hypothesis is not fully confirmed as originally theorized. While no credible evidence was found for presence level differences between peripheral and central cues, they do not demonstrate the consistent hypothesized improvement in user attention, or workload, when compared as positioning categories. The hypothesis would require reformulation to focus on specific design implementations rather than spatial positioning as the primary factor.

4.3.3.4 Summary

All-in-all, these findings suggest that the relationship between cue positioning and user attention in virtual environments is more complex than initially hypothesized. While this analysis did not reveal any significant difference in presence levels across both cue types, their effectiveness in drawing attention is greatly contingent upon thoughtful design implementation, and not on cue positioning alone.

The workload analysis provides additional insight, revealing that peripheral cues can potentially reduce cognitive demand when properly designed, but can also impose elevated cognitive workload, if poorly implemented. Once again, this cognitive efficiency variability further emphasizes the importance of design characteristics rather than spatial positioning on overall workload within IVEs.

The hypothesis receives partial support in that peripheral cues can be implemented without detriment to workload, but the impact on attention guidance and presence preservation claims require at the very least further investigation, with more systematic examination approach on the interaction between cue positioning and other design characteristics.

Chapter 5

Limitations, Future Work and Conclusion

This study successfully investigated the effectiveness of peripheral versus central visual cues in immersive virtual environments by carrying out a comprehensive experimental study that involved 24 participants across four distinct cue conditions. The study also employed rigorous methodological approaches, such as systematic counterbalancing of cue testing to eliminate order effects, within-subjects testing to control for any individual differences, and various measurement types including both objective and subjective metrics. Furthermore, the identified gap in IVE design was addressed, by providing evidence on whether peripheral positioning could maintain attention guidance effectiveness while preserving immersive experience quality and low cognitive workload. The comprehensive data collection framework, combining reaction time measurements, task completion metrics, presence evaluations, and workload assessments, allowed this study to offer valuable insights for future VR interface development.

5.1 Project Limitations

Several constraints emerged during this study that should be acknowledged, as they may have affected the quality, and specifically generalizability, of the findings:

5.1.1 Sample Size and Data Reduction

The study was conducted with a total of 24 participants, which represents a relatively small sample size for drawing definitive conclusions about visual cue effectiveness in virtual environments. This limitation was further compounded by the outlier removal process, which although only affected a total of 3 unique participants, still eliminated six extreme outliers from the dataset and effectively reduced the analysed data points for certain metrics. The combination of limited participants and subsequent data reduction may have affected the statistical capability to detect subtle, but perhaps meaningful, differences between cue conditions. This was especially notable in the IPQ presence results, where no comparisons were deemed of statistical significance. Additionally, the participant recruitment process did not systematically control for demographic diversity, with the sample consisting primarily of young adults without a systematically balanced representation across gender, age groups, or VR experience levels. This convenience sampling approach may limit the value of findings to broader user populations with varying characteristics and technological backgrounds.

5.1.2 Limited Cue Variety and Measurement Issues

The experimental design included only two central cues and two peripheral cues, which could be considered a narrow sampling of the broader design space for visual guidance systems in virtual environments. This limited selection may not capture the full range of potential effectiveness variations within each positioning category, as different visual designs, interaction modalities, or even aesthetic approaches could yield different results. Moreover, post-experiment feedback revealed significant participant confusion regarding some aspects of the experiment, namely the IPQ items, which saw many participants expressing uncertainty about the meaning and / or intent of specific questions. This comprehension difficulty likely introduced, to some extent, response variations that may have obscured genuine differences between the cue conditions tested. The relatively repetitive and short exposure time to each cue condition (seven rounds per phase) may have also been insufficient for participants to fully adapt to different guidance approaches or develop meaningful presence experiences.

Moreover, the use of English questionnaires for participants who may have had lower levels of English proficiency likely contributed to some comprehension difficulties. This idea is supported by some comments left by participants on the final questionnaire, all of which had Portuguese as mother tongue. Given the IGROUP website does not provide an official Portuguese version, the decision was made to carry out the full experiment, including questionnaires, in English. In hindsight, providing validated translated questionnaires according to participants' native languages could have been a more appropriate approach, and potentially have reduced response variations.

5.1.3 Methodological Constraints

While controlling for individual differences by testing every possible combination of cue order, the within-subjects experimental design may have introduced order effects and learning influences that affected performance across some of the cue conditions. Furthermore, the experimental task focused specifically on object identification and selection within a static and controlled virtual environment, which may not generalize to other common VR interaction scenarios such as navigation, manipulation, or more complex decision-making tasks.

Collectively, these limitations most likely than not affected the finding's generalizability. The small sample size and measurement sensitivity issues may have prevented the detection of subtle but still meaningful differences between central and peripheral cues, while the limited cue variety made it difficult to generalize findings to the broader category of peripheral visual guidance systems.

5.2 Future Work

The findings from this investigation open several promising paths for future research that could address the identified limitations, while also expanding the understanding of peripheral visual guidance techniques in immersive virtual environments.

5.2.1 Methodological Improvements

Future studies should employ considerably larger sample sizes to increase statistical power and consequently enable detection of smaller effect sizes that may be meaningful. A more thorough and systematic method of recruiting user testers should also be applied, ensuring systematic demographic diversity across age groups, gender, and ideally even VR experience levels, to improve generalizability of findings. Furthermore, alternative experimental designs could be explored in future studies, in order to address some specific methodological concerns, such as by exploring between-subjects approaches to eliminate order effects. This, however, would most likely require larger sample sizes and potentially introduce individual difference variations that the within-subject design used in this study effectively controls for. Future research could also explore more direct approaches for measuring presence, providing more objective indicators on immersiveness without relying on subjective answers. These could include, for example, physiological data collection methods (heart rate variability, skin conductance, or even eye-tracking metrics). Such approaches would obviously require validation studies to establish whether or not they reliably correlate with immersive experience quality, in the context of VR.

5.2.2 Expanded Research Directions

Research should systematically explore a broader range of visual cue designs within both central and peripheral categories to better understand the interaction between positioning and design characteristics, and the weight each has on final results. This could include investigating additional visual modalities, varying levels of abstraction, dynamic versus static cues, and adaptive systems that respond to user behaviour within the IVE. Future investigations should also examine visual cue effectiveness across diverse VR interaction scenarios beyond object identification tasks. An interesting example could be complex problem-solving environments or multitasking, where cognitive load differences between cue types may become more pronounced, as the relatively simple tasks in this study may have not been sufficiently demanding to reveal more subtle variations in imposed cognitive workload by the different cues. Other potentially interesting VR interaction scenarios that could be worth exploring are navigation tasks, educational applications, and perhaps even collaborative virtual spaces. Additionally, future research should aim to investigate visual cue effectiveness in an environment that better reflects real-world VR application contexts. These future studies should examine cue performance when environmental distractors are present, such as lighting conditions and other interface elements that would typically be present in more commercial VR applications.

5.3 Conclusions

This research investigated the effectiveness of peripheral versus central visual cues in immersive virtual environments, examining their impact on user attention, presence, and overall workload. Through a comprehensive experimental study that involved four distinct visual cue approaches, the research provided valuable insights into the complex relationship between visual guidance design and user performance within IVEs. Experimental results revealed that effectiveness of visual cues in virtual environments is primarily determined by design characteristics, rather than spatial positioning alone. While the original hypothesis proposed that peripheral cues would effectively draw user attention without compromising presence or perceived workload, the findings demonstrate a more nuanced situation, where cue design quality supersedes positioning effects. Performance metrics showed that well-designed cues achieved superior results regardless of whether they were positioned on the centre of participants' screen or on its periphery. Specifically, the Floating Arrow (central) and Swarm (peripheral) cues demonstrated superior performance compared to Floating Text (central) and Edge Lighting (peripheral), likely due to their more intuitive directional guidance and feedback mechanisms.

The presence and workload findings provide encouraging evidence that peripheral cues may be implemented without detectable detriment to immersive experience quality. IPQ presence component measures showed no statistically significant differences between central and peripheral cue conditions, indicating cue positioning did not have a detectable effect on spatial presence, involvement, experienced realism, and overall perceived presence. However, further testing across different VR experiences, ideally in different contexts, would be needed to establish a broader generalizability of these finding. Regarding the proposed research questions, the study found that positioning alone does not provide consistent attention guidance advantages, once again with other design implementation decisions of cue emerging as the primary determinant of effectiveness. Furthermore, the research hypothesis received partial support, with limited result support for attention improvement claims. While this outcome differs from initial expectations, it still provides valuable insights that redirect focus toward the critical importance of cue design quality when dealing with visual guidance systems and techniques.

Finally, this research provides several actionable insights for virtual reality and immersive virtual environment designers for future work on the topic. The finding that no detectable negative effect in presence preservation observed across positioning options might give VR application designers flexibility to place visual cues based on more strict contextual requirements, without immersion deterioration concerns. The importance of design clarity over positioning might also indicate that development resources should be allocated to creating intuitive, easily interpretable guidance elements.

All-in-all, this study establishes a strong foundation for a more flexible and user-centred VR interface design, ultimately advancing towards a more natural, and effective, human-computer interaction in virtual environments.

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Appendix A

Developed Questionnaires

A.1 Demographics and Baseline Questionnaire (Pre-test)

User Test Questionnaire

As part of the user test for the "Visual Cues for Attention Guidance in VR" 2025 thesis project at FEUP carried out by student Ricardo Pinto, supervised by Prof. Daniel Mendes and Prof. Teresa Matos:

I declare that I understood the explanation given to me about the study in which I will participate, namely the voluntary nature of this participation, having been given the opportunity to ask the questions I deemed necessary.

I understand that the information or explanation provided to me covered the objectives, methods, possible discomfort and the absence of risks to my health, and that maximum confidentiality of the data will be ensured.

They also explained to me that I could leave the study at any time, without any consequences.
Therefore, I consent to participate in the study and answer the presented questions, as well as recorded content.

up201806849@g.uporto.pt Mudar de conta

Não partilhado

* Indica uma pergunta obrigatória

Age *

A sua resposta

Gender *

- ◯ Male
- ◯ Female
- ◯ Prefer not to say
- ◯ Outra: ____

Vision Conditions *

Reminder: If you require glasses / contact lenses, you should use them in the VR experiment.

- ◯ I have no vision issues
- ◯ I have vision issues, but they are corrected with glasses or contact lenses
- ◯ I have vision issues, but not are corrected

How would you rate your previous experience with VR? (Before today)

Selecionar ▾

Previous VR Experience - Details

How long have you owned a VR device? *

- ◯ I've never owned a VR device
- ◯ Less than 6 months
- ◯ 6–12 months
- ◯ 1–2 years
- ◯ More than 2 years

In the past year, how frequently did you interact with the following types of VR experiences? *

	Never	A few times a year	Once a month	Once a week	Every Day
Smartphone inside VR headset	○	○	○	○	○
VR headset - head movements only (no body movements)	○	○	○	○	○
VR headset - head + body movements	○	○	○	○	○

For what purposes have you used VR devices for?

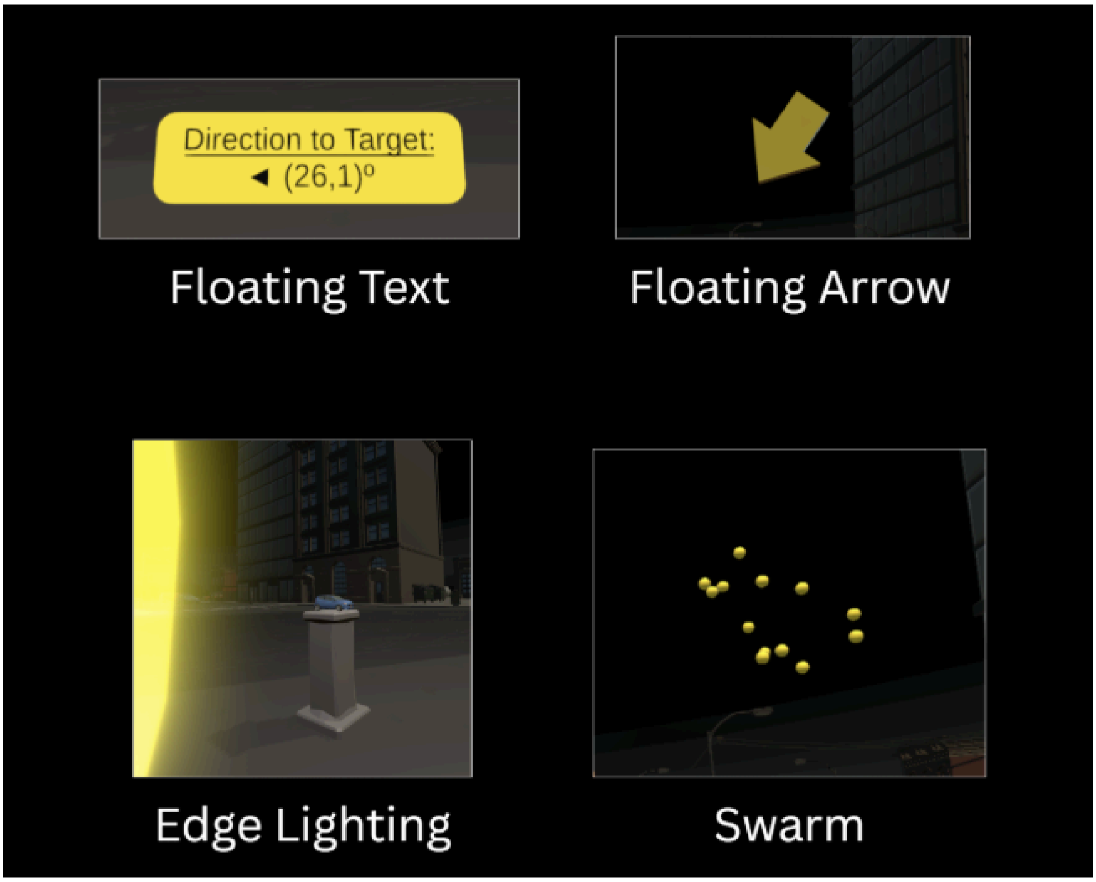
(If you haven't used VR before, ignore this question)

- ☐ Gaming
- ☐ Education / Training / Learning
- ☐ Work / Research / Development
- ☐ 360º Images / Videos
- ☐ As a participant of user studies (like this one!)
- ☐ Outra: ____________

A.2 Cue Preference Ranking Questionnaire (Post-test)

Cue Comparison (End of Experiment Questionnaire)

The different cues in the experiment



Rank the four cues from most effective (#1) to least effective (#4) at **guiding your attention to target objects**. *

	Floating Text	Floating Arrow	Edge Lighting	Swarm
#1 (Most Effective)	○	○	○	○
#2	○	○	○	○
#3	○	○	○	○
#4 (Least Effective)	○	○	○	○

Rank the four cues from **most natural/well-embedded in the environment**. *

	Floating Text	Floating Arrow	Edge Lighting	Swarm
#1 (Most natural/well-embedded)				
#2				
#3				
#4 (Least natural/well-embedded)				

Rank the four cues from least **distracting** (#1) to most **distracting** (#4). *

	Floating Text	Floating Arrow	Edge Lighting	Swarm
#1 (Least Distracting)				
#2				
#3				
#4 (Most Distracting)				

Rank the four cues from **most comfortable** to use (#1) to **least comfortable** (#4). *

	Floating Text	Floating Arrow	Edge Lighting	Swarm
#1 (Most Comfortable)	○	○	○	○
#2	○	○	○	○
#3	○	○	○	○
#4 (Least Comfortable)	○	○	○	○

Rank the four cues from **least disruptive to your sense of presence** (#1) to most disruptive (#4). *

	Floating Text	Floating Arrow	Edge Lighting	Swarm
#1 (Least Disruptive)	○	○	○	○
#2	○	○	○	○
#3	○	○	○	○
#4 (Most Disruptive)	○	○	○	○

Rank the four cues based on your **overall preference** from most preferred (#1) to least preferred (#4). *

	Floating Text	Floating Arrow	Edge Lighting	Swarm
#1 (Most preferred)	○	○	○	○
#2	○	○	○	○
#3	○	○	○	○
#4 (Least preferred)	○	○	○	○

Do you have any comment about one (or more) of the 4 cues tested in the experiment?

A sua resposta