The Importance of Cueing While Visually Searching a 360 Degree Environment for Multiple Targets in the Presence of Distractors

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Figure 1: In this study, four cue conditions were evaluated for a 360° visual search task with multiple targets and distractors: Gaze Line (left), 3D Arrow (middle), 2D Wedge (right), and a baseline No Cue condition (not pictured).

Abstract

Visually searching for objects is an everyday task. In many contexts, people must visually search for multiple objects at the same time while avoiding distractor objects, such as triage during a mass casualty incident. While many prior augmented reality (AR) and virtual reality (VR) studies have investigated cues to aid in visual search tasks, few have investigated cues in contexts involving multiple targets and distractors with a full 360° effective field of regard (EFOR). Individually, multiple targets, distractors, and a full 360° EFOR each add complexity to visual search; when combined, they compound the difficulty even further. In this paper, we present such a study that compares three common types of visual cues (2D Wedge, 3D Arrow, and Gaze Line) to a baseline condition with no cueing for a 360° visual search task. Our results reinforce the importance of providing some type of cue, with the Gaze Line design being particularly beneficial. We discuss the potential implications of these findings for designing cues specifically for such complex visual search tasks.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; *Information visualization*; **Virtual reality**; User interface design.

Keywords

Augmented Reality, Virtual Reality, Visual Cueing, Visual Search, Information Processing, Attention

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1 Introduction

An important advantage that virtual reality (VR) and augmented reality (AR) technologies afford is assisting users via cues. Several prior studies have used cues to assist in a variety of tasks, including visual search [24], wayfinding [36], assembly [25], training [1], and user tutorials [20]. Many of these cues have been shown to provide beneficial increases in performance (i.e., faster search time, higher accuracy, etc.). However, not all cues are created equal, and the context surrounding their use, such as the task, how the cues are presented, the number of targets present, or the presence of distractors, may affect the efficacy of the cues.

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Our work furthers knowledge in this area by exploring a visual search task with both **multiple targets** and **distractors** present in a **360° effective field of regard (EFOR)** virtual environment. Multiple target contexts are more complex than searching for a single target as the user must continue to attend to the environment even after discovering the first few targets. The addition of distractors further complicates this matter, as distractors, by the nature of their presence, draw attention from the user; thus requiring them to devote valuable cognitive resources to the distractor rather than the true targets. A 360° EFOR not only provides a larger search field, but also has the potential to introduce directional ambiguity to some cue designs, such as with the 3D arrow noted by Kelley et al. [21]. However, rather than cueing all targets simultaneously, we utilize an algorithm to select the closest target to the user's field of view (FOV), similar to the prior works of Liu et al. [27] and Seeliger et al. [40]. Results from our study emphasize the importance of utilizing cues for 360° EFOR search tasks with multiple targets and distractors present.

Results from our study demonstrate the benefits of visual cueing for 360° EFOR visual search tasks when the user must search for multiple targets while in the presence of distractors. Our work provides the following contributions:

- Evaluated cues in the context of *360° EFOR*, with both *multiple targets* and *distractors* present; a combination of factors that has not been thoroughly explored.
- Demonstrated the benefits of cues for these contexts and emphasizes the benefits for high stakes contexts, such as search and rescue, medical triage, or military usage.

2 Related Work

We discuss prior studies investigating cues for visual search tasks based on an extensive literature search. Table 1 provides an overview of these studies and the current paper.

2.1 AR/VR Device and Effective Field of Regard

As seen in Table 1, head-mounted AR and VR devices have been almost equally utilized for investigating visual search cues. Of the reviewed studies, 15 employed a head-mounted AR system, such as the Microsoft HoloLens 2 ([24, 41, 47]), and 13 used a head-mounted VR system, such as the HTC Vive Pro ([2, 8, 32]). On the other hand, only four studies investigated handheld AR devices, such as smartphones [35] and tablets [48].

Field of regard (FOR) refers to the total size of the display's visual field surrounding the user [7]. However, while most AR and VR displays now afford 360° FOR, some applications leverage smaller portions of the visual field, which we refer to as the effective field of regard (EFOR). While most of the prior studies employed applications that leveraged the entire environment surrounding the user (i.e., 360° EFOR), some studies focused only on the environment directly in front of the user (i.e., 180° EFOR or less) [15, 27, 35]. In the current study, we investigate a full 360° EFOR surrounding the user by employing a VR HMD and application. We chose to use VR, as opposed to AR, because it allowed us to easily implement an adaptive target selection algorithm without concerns regarding sensing or computer vision errors (i.e., errorless adaptive cueing).

2.2 Target Cueing

The vast majority of prior studies have investigated cueing targets sequentially (i.e., one at a time), often based on predefined sequences or configurations of targets. In some studies, these sequential targets are effectively the only objects of concern within the user's EFOR, either due to the targets being the only virtual objects within an AR application [6, 11, 12], or the only objects within a VR application [8, 46]. However, most prior studies have employed sequential cueing with distractors (i.e., non-target objects similar to the target). This is often to better capture realistic visual search tasks, where distractors take time and cognitive resources to process while trying to identify actual targets [50]. For instance if an individual is trying to find a person buried under an avalanche any mound of snow may contain the person being sought out; attending to any of the empty mounds would take time and effort from would-be rescuers.

In addition to sequential cueing, some studies have investigated simultaneous cueing, in which multiple targets are cued at the same time and the user decides in which order to select the targets. Perea et al. [35], Kumaran et al. [24], and Bork et al. [6] investigated such simultaneous cueing, but with an absence of distractors; an important factor for real world visual search applications. Additionally, the approach for multiple target cueing is to simply cue every target persistently, however this runs the risk of overwhelming the user through screen clutter [30]. Seeliger et al. [40] investigated searching for multiple targets with the presence of distractors, however there work limited the EFOR to 180°, and was primarily focused on gaze behavior and visual attention outcomes rather than performance (i.e. search time, search accuracy, etc.). A different study by Volmer et al. [45] did utilize a full 360° EFOR and contained multiple targets, however this work was rooted in precueing, where targets are sequential with the next N targets cued for the user [1, 45] and did not utilize distractors. To the best of our knowledge there has been no study that explored multi-target visual search with the presence of distractors in a 360° EFOR.

Additionally, few prior works have implemented adaptive techniques for cueing. Adaptive techniques utilize the context of the user, environment, and/or task to drive an aspect of cueing; this may be target detection [37, 47], cue activation [41], or, as presented in this work, target selection. In separate research, Seeliger et al. [41] and Harris et al. [18] employ adaptive techniques to determine whether a cue is provided for the current target (i.e., cue activatsion or whether to show or hide a cue). However, their targets are otherwise cued sequentially. To the best of our knowledge, Liu et al. [27] are the only researchers to date to investigate adaptive cueing for determining which target is cued among multiple targets, which is similar to the approach used in our study, where we employ an FOV-based cueing algorithm to dynamically select targets based on the user's FOV. In their study, Liu et al. [27] investigated two different adaptive cueing mechanisms, one based on hand proximity and one based on eye gaze, for unordered bimanual manipulation tasks, however, unlike our presented work, which utilizes a 360° EFOR, Liu et al. [27] utilized a 180° EFOR.

2.3 Cue Designs

Most prior studies have evaluated one or more cue designs by comparing them to some baseline condition. Numerous studies

Table 1: Overview of visual search cue studies. A ✓appears if a factor was explored. Cue conditions marked with ✓ were found to be significantly faster than conditions marked with x. Conditions marked with ● were not significantly different. "EFOR"="Effective Field of Regard". "Dis."="Distractors". *Multiple studies in one.

	Device			EFOR		Target Cueing				Cue Designs and Conditions													
Study	**Handheld AR**	**Head-mounted AR**	**VR**	**180°**	**360°**	**Sequential**	**Sequential w/ Dis.**	**Simultaneous**	**Simultaneous w/ Dis.**	**Baseline**	**Center Arrow(s)**	**Around Arrows**	**World Arrows**	**Halo**	**Wedge**	**2D Radar**	**3D Radar**	**EyeSee360**	**Gaze Line**	**Bounding Box**	**AroundPlot**	**Attention Funnel**	**Other(s)**
[14]		✓			✓	✓							●					●					
[18]			✓	✓		✓				●													●
[41]		✓			✓	✓				●													●
[46]			✓		✓	✓				x	✓					✓							✓
[8]			✓		✓	✓				x	✓					x							✓
[11]		✓	✓		✓	✓								✓	x								
[12]		✓			✓	✓						x		✓	x								
[45]					✓	✓																	✓
[48]	✓				✓		✓				✓			x					x				
[5]	✓				✓		✓					✓		x									
[15]		✓		✓	✓		✓			x								x					✓
[47]		✓		✓			✓			x	✓					x							
[21]		✓		✓			✓			x	x				x				✓				
[22]		✓		✓			✓			x	x				x				✓				
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[4]		✓			✓		✓			x										x		✓	
[13]		✓			✓		✓				x			x	x			✓					
[3]		✓			✓		✓				x												✓
[2]			✓	✓			✓			x			x							✓			
[38]			✓		✓		✓			x	✓											✓	✓
[32]			✓		✓		✓			x	✓												x
[29]*			✓		✓		✓			x									✓				
[29]*			✓		✓		✓			x									✓				
[51]*			✓		✓		✓				✓				✓	x	x						
[51]*			✓		✓		✓				✓				✓		x						
[17]			✓		✓		✓				✓						✓						✓
[35]*	✓				✓		✓					✓		✓							x		
[35]*	✓			✓				✓				●		●							●		
[6]		✓			✓			✓			x						●	✓			x		x
[24]		✓			✓			✓		x			✓			x							x
[27]			✓	✓				✓															✓
[40]		✓			✓				✓	x	✓		✓	✓	●					●			
Ours			✓		✓				✓	x	●				✓				✓				

have used a "no cue" condition as their baseline [2, 8, 18, 22, 24, 29, 32, 41, 46, 47]. However, other forms of baseline conditions have included paper-based maps [15, 40], image-based cues [38, 47], and verbal instructions [4]. Outside of the studies utilizing adaptive cueing techniques [18, 41], all prior studies have found cueing interventions to be at least as effective as the baseline condition, although more often these cues provided a benefit [22, 29, 37, 47].

A multitude of cue designs have been previously investigated for visual search tasks. Numerous researchers have investigated using both 2D and 3D arrows for cueing targets [12, 22, 35, 40]. However, these arrow-based cues can be further categorized based on their placement. Many studies have investigated a single arrow centered within the user's FOV that points to the target, which we refer to as a center arrow. In some studies, multiple center arrows have been investigated for cueing multiple targets [6], while others have investigated arrows displayed around the border of the user's FOV [5, 12, 35], which we refer to as **around arrows**. In other cases, researchers have investigated arrows positioned within the world, possibly outside of the user's FOV, which we refer to as **world arrows** [2, 14, 24, 40]. It is due to this prevalence in prior research that a 3D center arrow cue design was included in our study.

Several researchers have investigated cue designs originating from the user's FOV and extending toward the target, such as Gaze Lines [22, 29], wedges [13, 22, 51], or attention funnels [4, 38, 39]. With these designs part of the cue is always visible in the user's FOV and directs toward the target, then, once the target is in view the full cue stimuli is visible. Both 2D wedges and 3D wedges, in the form of triangles and pyramids, respectively, have been investigated [11–13, 21, 22, 40, 51]. Attention funnels, a series of frames creating a tunnel from the user's FOV to the target, were one of the earliest cue designs investigated [4, 38, 39] and show the user a "path" towards the target location. Most recently, the gaze line design, which is a simple line extending from the user's FOV to the target, was found to be significantly better than other cue designs [21, 22, 29]. The effectiveness of this classification of cue design motivated the inclusion of the Gaze Line and a 2D Wedge design in our work.

Radar designs have also been explored as visual search cue concepts. The most basic radar design is a 2D radar map similar to those found in many video games, which have been investigated by several researchers [8, 19, 24, 46, 47]. A slightly more-advanced radar design is the 3D radar, which conveys horizontal and vertical positions of targets relative to the user's position [6, 51]. Another radar-like design is EyeSee360, which maps the yaw and pitch of a target relative to the user's FOV to the longitudinal and latitudinal lines, respectively, on a world map-like visualization [6, 13–15, 19]. There are other cue designs that were investigated across multiple studies. One of them was Halo, which displays a 2D circle emanating from the target that falls within the user's FOV, has been evaluated in several studies [5, 11–13, 35, 40, 48]. Another example is Bounding boxes, in the form of 2D outlines or 3D semitransparent volumes, have also been investigated by multiple researchers [2, 4, 39, 40]. Another cue design is AroundPlot, which displays targets as dots around the border of the user's FOV [6, 35]. Outside of these designs and the ones described above, researchers have investigated a wide variety of cues for visual search, including labels [15], luminance [32], 3D sounds [3], and haptic feedback [32]. While radar designs were considered for this study pilot testing favored other designs that were then selected.

A large number of prior works only explored sequential targeting, where only one target was presented at a time [2–5, 8, 11–15, 17, 18, 21, 22, 29, 32, 35, 38, 39, 41, 46–48, 51]. However, users often search for multiple objects within their environment. The addition of multiple targets creates a more realistic, and complex, search task [6, 24, 27, 35, 40]. Distractors can further complicate such tasks as users must devote precious cognitive resources to discerning between true targets and the distractors [2–5, 13, 15, 17, 21, 22, 29, 32, 35, 38–40, 47, 48, 51]. The EFOR can affect how far a user must move or turn before a target is in their FOV, as such a 360° EFOR [3–6, 8, 11–15, 17, 24, 29, 32, 35, 38, 40, 41, 46, 48, 51] will require more time and effort to survey than a 180° EFOR [2, 15, 18, 21, 22, 27, 35, 39, 47]. **Our study combines each of these factors, which creates a more complex task that is more reflective of many real world scenarios, such as search and rescue, military operations, or first responder operations and has been understudied in the current literature.**

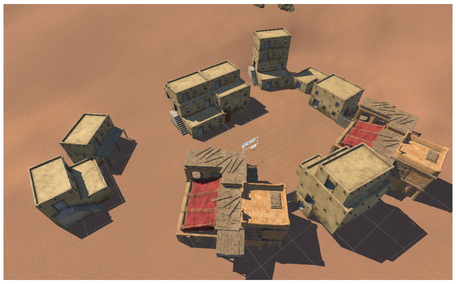
Figure 2: A top-down view of the search environment.

3 Methods

To assess the benefits of cueing, a VR test bed environment was developed for the Meta Quest Pro VR-HMD that allowed unrestricted movement within an 8m by 8m virtual boundary. Using this application, participants completed a visual search task with four cue conditions (no cue, Gaze Line, 2D Wedge, and 3D Arrow), which was approved by our institution's internal review board. An algorithm determined the target cued by the system. A variety of measures were collected during the searches, including time, accuracy, and reported mental demand (via the Paas scale [26, 33, 34]). Additional interaction data (i.e., user position, user gaze, target location, etc.) was collected during each frame.

3.1 Apparatus

A VR application was developed for the Meta Quest Pro VR-HMD using Unity (version 2022.22.1f). A virtual environment consisting of several buildings of varying heights (1 - 3 stories) were placed at varying distances from the user's starting position (see Figure 2 for a top-down view). Some buildings were intentionally placed in a manner where portions of the building were partially obscured by other buildings from sections of the user's VR boundary. This was done to encourage movement throughout the space. The environment afforded 70 total windows and doorways to be used as search locations.

Each search location was encoded numerically (1 through 70). A plain text configuration file was used to control the placement of targets and distractors. Each file line contained ten numeric values for the target locations and twenty numeric values for the distractor locations. These target and distractor numeric values were compared to the search location numeric values when resetting the environment for the next search. Once the file was iterated through, the next cue condition would automatically begin and the configuration file lines would be randomly shuffled using a random without replacement approach.

3.2 VR Task Design

During a visual search, ten targets were placed in search locations within the environment. An additional 20 distractors were also placed in separate search locations. These distractors varied in their similarity to the search target. The exact location of the targets and distractors was controlled by a configuration file. This file was configured such that there were 14 different environment configurations. This allowed for each search location to be used twice, during the span of the entire search condition (i.e., a window encoded as search location 22 would contain a target in two separate search configurations).

Figure 3: Left: the search target, 10 are present in any given search configuration. Right: distractor examples, 20 are present in any given search configuration each with different levels of similarity to the search target (i.e., a high similarity target wearing the same green jacket and a grey cap; a low similarity target wearing a tan tank top).

Once a target was found, the user would place a marker at the target location by pointing at the search location with a virtual laser pointer protruding from either the right or left controller and pressing the corresponding trigger button. This marker was visualized as a blue sphere with a radius of 0.125m. These markers could also be deleted by pointing at an already placed marker with a laser pointer and pressing the trigger button on the corresponding controller. Once the user believed all targets in the current environment were located, they would press either the "b" or "y" button (also classified as the secondary button) on the face of one of the controllers to change to the next search configuration. Participants were not told how many targets they would be searching for and any unmarked targets would be classified as "missed." This was an intentional design choice to better simulate real world search conditions in which individuals are often not privy to how many targets would be present in high stakes scenarios, such as military operations, search and rescue, emergency medical operations, etc. No time limit was given on completing any search. The exact order of the 14 search configurations was randomly shuffled for each user and between each condition using a random without replacement approach.

Whenever a user utilized a cue to assist in searching an algorithm selected which target to cue. Placing a marker at or near (within 3 meters) a target location would automatically remove the current cue. The system would then create a new cue instance and select the next target. Our algorithm selected the next target by giving priority to 1) any target currently in the participant's field of view (FOV), 2) followed by any target currently in front of the participant (but outside of their FOV), and finally, 3) any target residing behind the participant. This particular implementation was developed with the assumption that real-world cueing would primarily utilize forward-facing RGB cameras commonplace on HMDs to sense the environment and aims to minimize the physical effort that may be required for searching. This approach also has the advantage of being orientation agnostic when resetting the search environment, as the first target chosen would always prioritize one of the closest targets in the user FOV. This in turn, limits the amount of excess movement required to find the initial cued target as opposed to a sequential approach. It also reduces the amount of spatial information that a participant is required to keep track of as opposed to a simultaneous cueing approach.

3.3 Pilot Testing

Along with a baseline No Cue condition, three cues were implemented for this experiment: Gaze Line, 2D Wedge, and 3D Arrow. **To assist in the selection of these cues a pilot study was conducted with 8 different cue conditions selected from prior literature.** The data collected during piloting, along with the reported results in prior literature led to the selection of the three cue designs used in this study.

3.4 Cue Designs and Conditions

The Gaze Line consists of a red line, 0.05m thick, drawn from an offset in the user's view, 0.5m in front of the user's camera and 0.25m above the center of their FOV, to the target location (see Figure 4a). Due to this design, the Gaze Line communicates both the direction and location of the target in reference to the user's current view and capitalizes on the 3D nature of HMDs. When the target is in the user's FOV the entire line can be seen, originating from the offset and terminating at the center of the target location. When the target is outside of the user's FOV the line originates at the offset and runs across their FOV terminating at the closest FOV edge to the target. Several prior studies have implemented the Gaze Line cue and demonstrated its potential for visual cueing (e.g., [21, 29]). In fact, a majority of the prior studies that utilized the Gaze Line found significant results (see Table 1). **Our pilot data also supported the Gaze Line as a particularly effective cue design.**

Prior studies have also demonstrated benefits to using the 2D Wedge design for cueing [16, 22]. This cue overlays a red 2D triangle, 1500 by 311 pixels in size, onto the user's view, with the base of the triangle always in the user's view, but offset 50 pixels from the center of the user's FOV and the tip of the triangle hovering over the target position transposed from the 3D space to the 2D space, using Unity's built in WorldToScreenPoint method, which converts world space coordinates to screen space coordinates (see Figure 4b). As the center of the user's FOV approaches the transposed target location, the triangle visualization scales in size, with the tip always over the target location. When the target is within the user's FOV the full wedge is visible with the base always 50 pixels from the center of the user's FOV and the tip overlaid over the target's transposed position. When the target is outside the user's FOV the base of the wedge is visible and the two long edges of the triangular shape converge to the offscreen location terminating at the edge of the user's FOV closest to the target. As with the Gaze Line, the 2D Wedge provides both direction and location information to the user, however it adds proximity by scaling as the center of the user's FOV approached the target position. Due to this the 2D Wedge communicates a third dimension of information to the user. Additionally, **in our piloting of cue designs, the 2D wedge provided the second most compelling results after the Gaze Line**.

Unlike the Gaze Line and the 2D Wedge cue, the 3D Arrow does not provide location information; only direction. The implementation of the 3D Arrow used for this study places a red 3D Arrow model, modeled after a javalin style arrowhead, in the user's view and rotates it around the same offset used for the gaze line to always point at the associated target location; a center arrow (see Figure 4c). Several variations of 3D Arrow cues exist, but all typically include the use of a 3D model pointing towards a target [5, 14, 48, 51]. **The inclusion of a 3D Arrow cue in this study is motivated by its prominence in prior research** [5, 14, 48, 51] and the exclusion of explicit position and proximity information in its design.

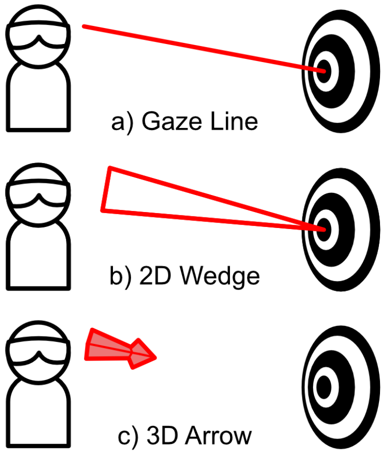

Figure 4: The a) Gaze Line, b) 2D Wedge, and c) 3D Arrow cue designs.

Our presented work builds upon prior literature by incorporating both multiple targets and distractors into a 360° EFOR visual search task. A combination of factors that, to the best of our knowledge, has not been explored. More targets in the search environment would increase the overall complexity of the search task, as more time, cognitive resources, and effort would be required to find all of the present targets. Distractors further complicates the task by diverting attention from the actual search task. A 360° EFOR also creates a larger search field that the user must examine to identify targets. Each of these factors compounds to create a more complex task with many facets that affect cueing outcomes. In prior works with multiple targets the approach is often to cue all targets simultaneously [5, 6, 24], however this may add screen clutter [30], further taxing the users' cognitive resources. Instead, we utilize an algorithm to drive target selection for cueing rather than cue all targets simultaneously.

3.5 Study Design

This study used a within-subjects design with 4 conditions (No Cue, Gaze Line, 2D Wedge, and 3D Arrow). The order in which the cue conditions appeared was counterbalanced using Latin Squares to control for learning effect. After consenting to participate, being briefed on the usage of the VR-HMD, and being granted a period to practice with the VR controls until they felt comfortable with placing and deleting markers, participants completed 14 search tasks per condition, each with 10 targets to find. This led to each participant searching for 560 targets (14 search configurations x 10 targets x 4 conditions) over the span of 56 trials (14 configurations x 4 conditions). The participants occupied a space approximately 8m by 8m in size and were allowed to move freely within these boundaries.

Between each condition, participants were asked to rate the level of effort required for the condition (using the Paas scale [26, 33, 34]) and were granted a 15 second break. The Paas scale [26, 33, 34] consists of a single likert scale question with a range of 1-9 to assess cognitive load. During the searches, the total search time for each configuration was collected, along with the average search time per target, the accuracy of markers placed, and the total amount of movement and rotation for the HMD, right controller, and left controller. After completing the searches, participants were also asked to share any questions, comments, or feedback.

3.6 Participants

A total of 23 participants were recruited for this study through university mailing lists and word of mouth; however, four of these datasets were excluded either due to technical problems (i.e., the HMD crashing/rebooting; 2 instances), improperly following task directions (1 instance), or being cut short after going over time (1 instance). This left a total of 19 participants: 9 self-identified as male, 10 as female, and none identified as non-binary or any other category. The average reported age was 23.21, ranging from 19 to 34. A little over half of the participants reported prior use of an AR headset ($N = 11$), but only 2 reported never using a VR headset before. Participants reported using a computer for work, school, or other purposes on average 38 hours per week. All participants were compensated with course credit or a $25 Amazon e-gift card.

4 Results

4.1 Search Time

Examination of QQ-plots for both average and total time indicated normality, so a repeated measures ANOVA was utilized with post-hoc analysis using Tukey's test. Both the average and total amount of search time were revealed to have statistically significant effects through repeated measures ANOVA ($F(3, 54)=3.06$, $p< 0.05$ for total search time and $F(3, 54)=5.82$, $p< 0.001$ for average search time). Both the Gaze Line (2.23s) and the 2D Wedge (2.42s) were found to be significant when compared to the No Cue condition (2.93s) for average search time, with a large effect for the Gaze Line and No Cue difference ($d = 0.88$) and a medium effect for the 2D Wedge and No Cue difference($d = 0.52$). No difference was found between the No Cue and 3D Arrow conditions or between the different cues. Additionally, only the Gaze Line cue was significant over the

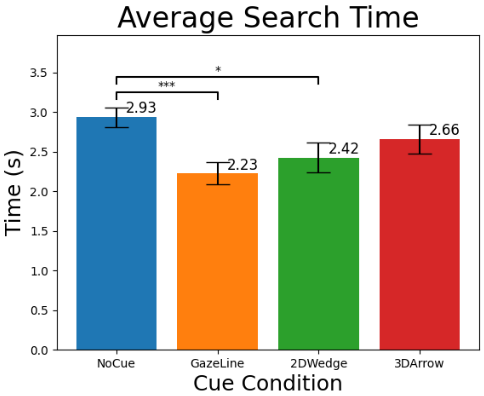

Figure 5: The average amount of time to find one target. Bars indicate standard error.

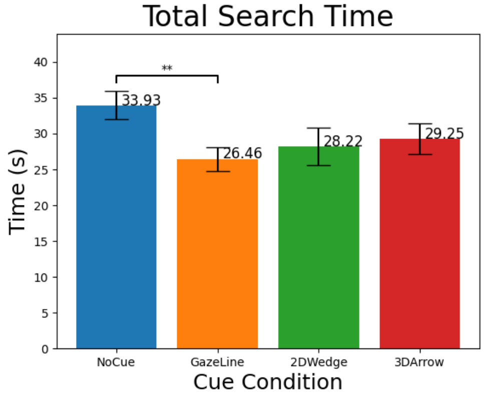

Figure 6: The total amount of time required to find all targets present in a scene. Bars indicate standard error.

baseline No Cue condition for the total search time results, with a medium effect size (d = 0.67). The Gaze Line was 7.47 seconds faster than the No Cue condition for total search time. See Table 2 for all search time and accuracy results.

Table 2: Average search time, total search time, and accuracy for each cue condition.

Cue	Avg	Total	Accuracy
No Cue	2.93s	33.93s	95.14%
Gaze Line	**2.23s*****	**26.46s****	**99.45%****
2D Wedge	**2.42s***	28.22s	**97.42%***
3D Arrow	2.66s	29.25s	**99.12%***

4.2 Accuracy

The highest accuracy was produced with the Gaze Line cue of 99.45%, followed by the 3D Arrow with an accuracy of 99.12%, then the 2D Wedge with an accuracy of 97.42%, and finally the No Cue condition with an accuracy of 95.14% . QQ-plots indicated a lack of normality for accuracy data, so the non-parametric Kruksal-Wallis test was utilized. This revealed a strong significance for accuracy $\chi^2(3) = 15.53, p < 0.01$. Post-hoc analysis using Dunn's test with Bonferroni adjustment revealed significant effects between the baseline No Cue condition and all three of the cued conditions (Gaze Line: $p < 0.01$, 2D Wedge: $p < 0.05$, 3D Arrow: $p < 0.05$). A small effect size, calculated with Cohen's D, was observed for the difference between No Cue and 2D Wedge (d = 0.26) and a medium effect size was observed for the differences between the No Cue and both the Gaze Line (d = 0.63) and 3D Arrow (d = 0.48).

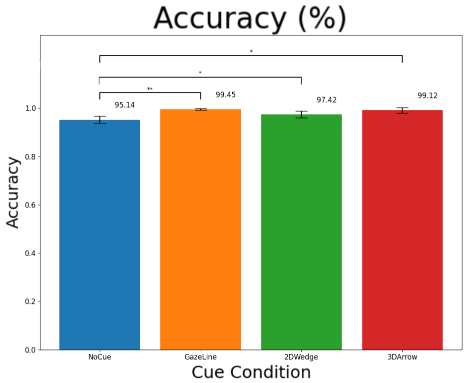

Figure 7: Accuracy of searches between cueing conditions.

4.3 Movement

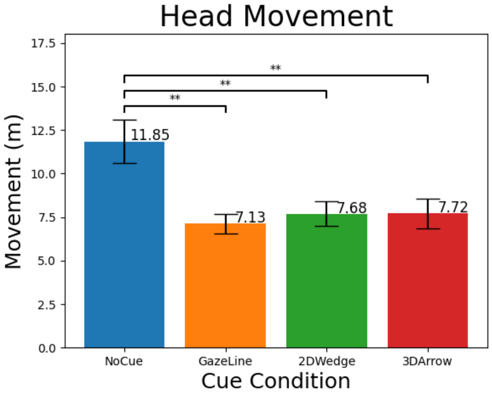

Figure 8: The total amount of head movement in meters.

Head movement (measured in meters) was found to be statistically significant (repeated measures ANOVA $F(3, 54)$=10.9, $p < 0.001$ with Tukey's test for post-hoc analysis) with medium effects between the No Cue condition and each of the cued conditions (Gaze Line (d = 0.79), 2D Wedge (d = 0.67), and 3D Arrow (d = 0.63)). Head rotation, on the other hand, was not found to be significant. All cues reduced the total amount of movement, dropping from an average movement of 11.85 meters to between 7 and 8 meters with the cued conditions.

This effect can also be seen in the movement of the right-hand controller (repeated measures ANOVA $F(3, 54)=6.63$, $p< 0.001$), and the movement of the left-hand controller (repeated measures ANOVA $F(3, 54)=6.81$, $p < 0.001$), although for the left-hand controller, the 2D Wedge did not produce a significant difference when compared to the No Cue condition, as it did with the head and right-hand controller. Participants moved their right hand between 0.3m and 1.17m more than their left hand on average, with the greatest difference being produced by the Gaze Line cue condition (right hand 12.46m of movement; left hand 11.29m of movement), and the lowest difference being produced by the 2D Wedge condition (right hand 11.21m of movement; left hand 11.91m of movement).

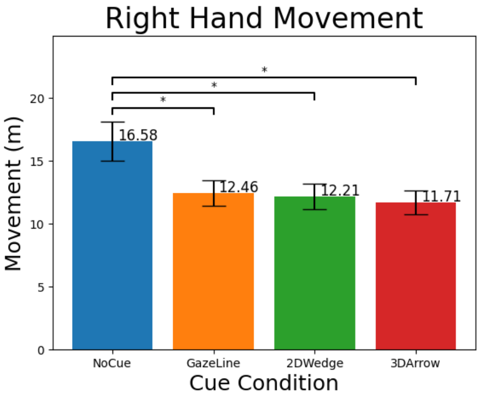

Figure 9: The total amount of movement in meters of the right hand controller.

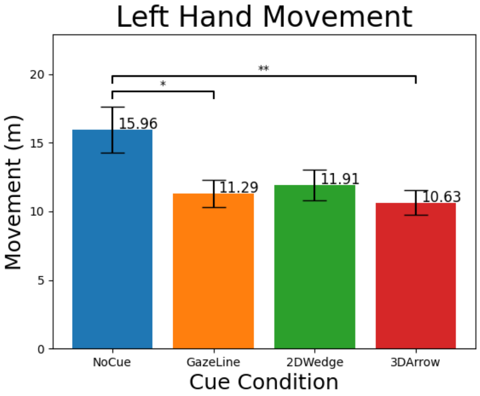

Figure 10: The total amount of movement in meters of the left hand controller.

4.4 Reported Mental Effort: Paas Score

Analysis of Paas scores using a Kruskal-Wallis test, due to lack of normality from QQ-plots, revealed a statistically significant result ($\chi^2(3) = 9.26, p < 0.05$), with a post-hoc Dunn's test revealing significant difference between the No Cue and Gaze Line, as well as between the Gaze Line and 2D Wedge conditions. A medium effect size was observed for both the Gaze Line (d = 0.72) and the 2D Wedge (d = 0.56) differences with the No Cue condition. The Gaze Line was ranked as the least demanding with a score of 3.42 (out of a possible 9), followed by the 3D Arrow (4.53), then the 2D Wedge (5.05), and finally, the No Cue condition (5.53). This sentiment of preferring the Gaze Line cue was also expressed in open-ended comments from participants after the conclusion of the trial, with individuals indicating a lack of preference for the 2D Wedge.

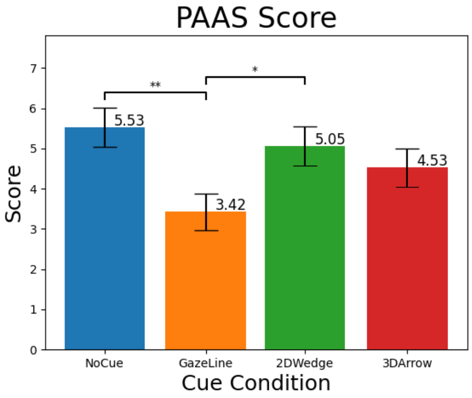

Figure 11: Paas score for each cue condition.

5 Discussion

The results from our study indicate the importance of using cues for 360° EFOR search tasks with multiple targets and distractors as search time, search accuracy, and subjective measures of effort all saw some benefit. Of particular interest is the Gaze Line cue, which produced the most favorable outcome over the baseline No Cue condition. Cueing also influenced the users' movement behaviour, most notable by reducing the amount of head maneuvers.

5.1 Cueing is Important for 360° Search Tasks

Each of the cue implementations led to an increase in search accuracy. While this increase in accuracy was not as pronounced as those found in some prior work [22, 37, 47], even a few percentage points can be crucial for time sensitive or hazardous tasks with visual search elements; such as triage after natural or man-made disasters, military operations, search and rescue, etc.

Even more important for time critical contexts is the response time. Even a few seconds can be the difference between life and death for first responders, military operations, or search and rescue. Both the Gaze Line and 2D Wedge improved on search time over the baseline No Cue condition. We attribute the reduction in overall benefit to the compounding complexity of having multiple targets, distractor objects, and a full 360° EFOR search environment. Each of which creates a more complex task in isolation, and compound complexity when used in tandem.

The lack of significant search time results from the wedge and arrow designs may be due to a variety of factors. First is the perceptual ambiguity that can occur when viewing the 3D Arrow head-on or from behind (such as with the necker cube optical illusion [23, 49]).

This phenomenon leads to difficulty in discerning if the target is in front of the user or behind them, which would then require more cognitive resources (and thus time) to determine the true location; an effect that would be more pronounced with a 360° EFOR. In the case of the 3D Arrow, the lack of position and proximity information may have increased the processing time required to find cued targets, as the exact position would need to be extrapolated by the user from the direction information communicated. Whereas position information was conveyed by both the Gaze Line and 2D Wedge.

For the 2D Wedge, this preference trend favoring the Gaze Line, may be due to the lack of intuitiveness behind the wedge design, with several participants mentioning confusion with the wedge cue when prompted for comments. This could be the product of too much information being communicated simultaneously by the 2D Wedge design, as it communicates direction (via converging lines), position (via the triangular point), and proximity (via scaling). These preferences are further supported by the Paas score results, showing lower effort required for the Gaze Line over the No Cue and 2D Wedge conditions.

The Gaze Line produced the most compelling results in our study, as it produced significant results over the baseline condition for total and average time, as well as accuracy. This is in line with prior studies that have also found the Gaze Line cue beneficial for various tasks [21, 29]. This benefit is further reinforced by the preferable Paas score rankings, with the Gaze Line condition requiring less reported effort from users.

5.2 Cueing Influenced Movement

The reduction in movement for the head may be due to participants' desire for accuracy. As the participant moved throughout the virtual space, there would inevitably be times when potential search locations were partially or even fully obscured by their current vantage point. If a cue was present to aid the user, this situation would be readily apparent. However, if they were currently searching with the No Cue condition, they would instead have to relocate to ensure that they did not miss any occluded targets. During experimentation it was observed that participants would often duck, lean forward/backward, or slide left/right when using the No Cue condition. A behaviour that was minimal when utilizing cues.

Differences in handed movement (i.e., right vs left hand) are most likely due to population differences in handedness, as only around 10% of the population is left handed [28]. While this study did not collect data on handedness this would explain the increased movement with the right hand as only 1 in 10 participants would be expected to be left handed leading to more individuals who would instinctively interact with the scene using the right controller. However, this does not account for the lack of significance for left hand movement when using the 2D Wedge, and the smaller difference between the right and left hand movement for the 2D Wedge. 2D Wedge results may be product of the higher reported mental effort for the 2D Wedge (see Figure 11). Several prior studies have linked higher cognitive load to an increase in mouse movement [10, 44], and this effect may be carrying over to motion controller movement.

5.3 Limitations and Future Work

Due to the use of a university population, there maybe limits to the generalizability of this work. Data related to ethnicity was also not collected. Additionally, participants were required to have 20/20 vision or corrected to 20/20 vision in order to participate, limiting generalizability for low-vision individuals. This limitation may be further compounded in a complex visual environment or in the case of optical see-through AR-HMDs in bright lighting conditions, which may increase the difficulty of discerning the cue from the environment.

In this study, the cue always pointed to a target location and never missed a target. However, if automated target detection were to be adopted, there may be erroneous cueing instances that may well affect the overall user performance, either by requiring more effort to discern the error and make the correct selection, or by introducing automation bias [9, 31, 37, 42, 43]; although this would also be dependent on the saliency of the cue. Additionally, users may become more effective at the search task over time, or even become accustomed to using a particular cue for the task.

There may be other design factors and choices not represented by the cues utilized in this study. Cognitive factors may be further influenced by the amount of visual information being communicated at any given time. This could be manipulated by cue design, but may also be affected by the number of simultaneous cues being presented, a factor not explored in this work. Additionally, the factors driving target selection were not explored in this work. While we did utilize an algorithmic selection process to minimize potential user movement, this would need to be compared to a different approach to discern any benefits.

6 Conclusion

This study presents a within-subject design with four cue conditions (no cue, Gaze Line, 2D Wedge, and 3D Arrow). The search task was completed in a 360 EFOR with the presence of both multiple targets and distractors; all of which increase a task complexity when in isolation and would have a compounding effect when presented in tandem. Data from a group of 19 participants who completed a visual search task with each cue condition indicated that incorporating visual cues into such tasks is important to improve task performance, with the Gaze Line condition providing the most significant benefits over the baseline No Cue condition. There also exist changes in user movement behaviour. Most notably the reduction in head maneuvers (e.g. ducking, leaning, sliding) when using cues. These insights are particularly valuable for high stress or high risk situations, such as first response and triage after man-made or natural disasters, military operations, or search and rescue, where time is of the essence.

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