2025 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) | 979-8-3315-1484-6/25/$31.00 ©2025 IEEE | DOI: 10.1109/VRW66409.2025.00257

Cuing Multiple-Targets for Visual Search in Virtual Reality

Brendan Kelley*
Colorado State University

Ryan P. McMahan
Virginia Tech

Christopher D. Wickens
Colorado State University

Benjamin A. Clegg
Montana State University

Francisco R. Ortega
Colorado State University

Abstract

Visual search is a common task, especially given the high amount of spatial information we process visually. To aid in searching an environment for targets, various cues have been developed and implemented for augmented reality (AR) head-mounted displays (HMDs). A variety of designs have emerged from prior literature including the gaze line, 2D wedge, and 3D arrow, each with unique design characteristics. However, many of these designs are not evaluated beyond their initial design proposals. Results favored the gaze line cue for search time, accuracy, and reported mental effort, potentially highlighting the benefit of having both direction and location information embedded into the cue.

Index Terms: Virtual reality, augmented reality, visual search, cues

1 Introduction

In this work, we build upon cueing works by presenting a study evaluating three different cues (gaze line, 2D wedge, and 3D arrow) and a baseline condition (no cue). During a search, participants were tasked with finding 10 targets among a set of distractors and placed a marker at the target location. Our findings support the gaze line as the fastest, most accurate, and easiest to process of the cues.

2 Related Work

Several prior studies have used cues to assist in a variety of tasks, including visual search [3], wayfinding [6], and assembly [4]. 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; the context surrounding their use, such as the task and cue presentation, may affect cue efficacy.

Prior studies investigating cues for visual search tasks have led to a rich variety of cue designs, such as the gaze line [3], 2D wedge [2], 3D arrow [1]. Most of these prior studies have evaluated cues in single-target contexts; where targets are cued sequentially, one at a time [3, 2]. In these studies, once a target was found, a new target was spawned and singularly cued. A few studies have evaluated cues in multi-target contexts, where multiple targets are simultaneously cued, either without [1] or with [3] distractors (i.e., other non-target objects), however these are much less prevalent. In these prior works, cueing was found to be at least as effective as un-cued searching.

2.1 Cue Designs and Conditions

Researchers have investigated the use of both 2D and 3D arrows for cueing targets. Many studies have investigated a single arrow centered within the user's FOV that points to the target (a center arrow design). In some studies, multiple center arrows have been investigated for cueing multiple targets [1]. Other researchers have investigated cue designs that originate from the user's FOV and extend toward the target: such as 2D wedges and 3D wedges [2, 7]. Most recently, the gaze line design, which is a simple line extending from the user's FOV to the target, has been found to be significantly better than other cue designs [3].

For the current study, we utilized the same cue designs recently compared by Kelley et al. [3]: gaze line, 2D wedge, and 3D arrow (centered). In their research, Kelley et al. [3] found that gaze line was significantly faster than 2D wedge, which was significantly faster than 3D arrow. However, unlike Kelley et al. [3] we apply these cues to a 3D VR environment.

3 Methods

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. The environment afforded 70 total windows and doorways to be used as search locations which were encoded with a numeric value (1 through 70). To control the placement of targets and distractors, a plain text configuration file was used. Each line of this file 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.

3.1 Study Design

This study used a within-subjects design with 4 conditions (no cue, gaze line, 2D wedge, and 3D arrow), which was approved by the Colorado State University Institutional Review Board. The order in which the cue conditions appeared was counterbalanced using Latin Squares. After consenting to participate, being briefed on the usage of the VR-HMD, and being granted a period to practice with the VR controls, participants completed 14 searches per condition, each with 10 targets to find. This led to each participant searching for 560 targets (14 search configs. x 10 targets x 4 conditions) over the span of 56 trials (14 configs. x 4 conditions). Between conditions participants were asked to rate their level of effort (using the Paas scale [5]) and were granted a 15 second break.

A total of 19 participants were included in this study. They were recruited through university mailing lists and word of mouth. Of these participants, 9 self-identified as male and 10 as female. The average reported age was 23.21, ranging from 19 to 34. A little over half of participants reported prior use of an AR headset ($N = 11$), but only 2 reported never using a VR headset before. All participants were compensated with course credit or a $25 Amazon e-gift card.

4 Results

The highest accuracy was produced with the gaze line cue (99.07%), this was followed by of the 3D arrow (97.5%), then the 2D wedge (96.44%), and finally the no cue condition (94.06%). A

*e-mail: brendan.kelley@colostate.edu

979-8-3315-1484-6/25/$31.00 ©2025 IEEE
DOI 10.1109/VRW66409.2025.00257

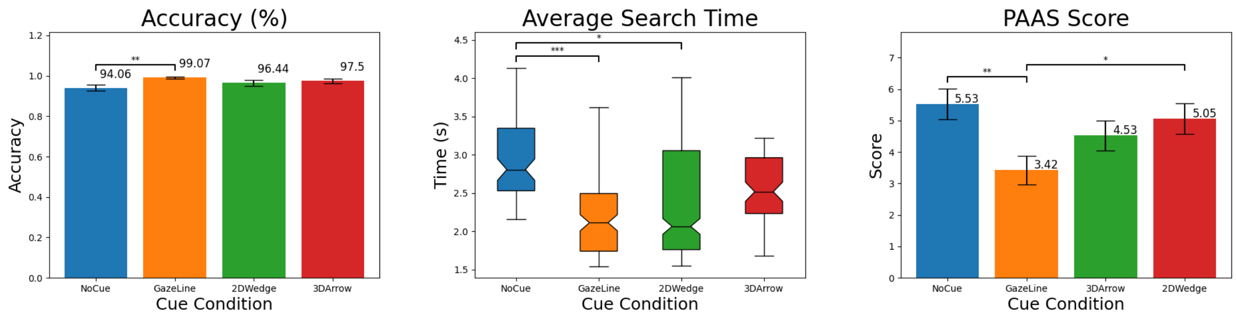

Table 1: Left: the accuracy with each cue condition. Center: the average time to find one target with each cue condition. Right: the reported PAAS scores with each condition.

repeated measures (RM) ANOVA revealed a statistically significant effect for accuracy ($F(3,54) = 5.20$, $p < 0.01$). Post hoc analysis (Bonferroni correction) shows a significant effect between the no cue and gaze line condition ($p < 0.01$) and a large effect size (Cohen's d, $d = 0.8$).

The gaze line cue produced the fastest average search times (2.23 seconds for each target). The condition with the second fastest search time was the 2D wedge (2.42s). This was followed by the 3D arrow condition (2.66s). All cues produced a faster search time over the no cue condition, which had an average time of 2.93 seconds. The average search time was revealed to be statistically significant through RM-ANOVA ($F(3,54) = 5.82$, $p < 0.001$). Both the gaze line and the 2D wedge were found to be significant when compared to the no cue condition 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($d= 0.52$).

Analysis of Paas scores revealed a statistically significant result ($F(3,54) = 3.57$, $p < 0.05$), with a 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 ($d = 0.56$). 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, no cue (5.53).

5 Discussion

The search time and the accuracy measures collected for the gaze line cue support it as the optimal choice in our use case. This is in line with prior studies that have also found the gaze line cue beneficial for various tasks [3]. This benefit is further reinforced by the preferable Paas score rankings, with the gaze line condition requiring less reported effort from users. Each of these factors, the lower search time, higher accuracy, and lower reported effort from users, indicate that the gaze line cue is a strong choice for tasks requiring visual search.

The lack of significant 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), which, in turn, requires more cognitive resources to process. Additionally, the 3D arrow lacks embedded position information; whereas, position information was conveyed with 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 initial confusion or lack of understanding as to how the wedge cue functioned. These preferences are further supported by the Paas score results, showing the least effort required for the gaze line followed by the 3D arrow, then the 2D wedge, and finally the no cue condition.

6 Conclusion

This study presents a within-subject design with four cue conditions (no cue, gaze line, 2D wedge, and 3D arrow). Data from a group of 19 participants who completed a visual search task indicates that the gaze line cue design not only provided the fastest response time and highest accuracy but also required the least effort to use. This preference for the gaze line cue may be due to the cue's simple and intuitive design that includes more spatial information than the 3D arrow cue. While the 2D wedge also included both position and direction information, the increased reported mental effort by users when using this cue seems to have hindered the benefits from including the extra spatial information.

Acknowledgments

This study was supported by ONR grants N00014-24-1-2214 and N00014-21-1-2580, and NSF grants 2238313 and 2444132.

References

[1] F. Bork, C. Schnelzer, U. Eck, and N. Navab. Towards Efficient Visual Guidance in Limited Field-of-View Head-Mounted Displays. *IEEE Transactions on Visualization and Computer Graphics*, 24(11):2983–2992, Nov. 2018. doi: 10.1109/TVCG.2018.2868584 1

[2] U. Gruenefeld, A. E. Ali, S. Boll, and W. Heuten. Beyond Halo and Wedge: visualizing out-of-view objects on head-mounted virtual and augmented reality devices. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*, pp. 1–11. ACM, Barcelona Spain, Sept. 2018. doi: 10.1145/3229434.3229438 1

[3] B. Kelley, C. Wickens, A. C. Warden, B. Clegg, and F. Ortega. 2D and 3D Augmented Reality Attention Cueing Comparisons in 3D Target Search. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, p. 10711813241265077, Aug. 2024. doi: 10.1177/10711813241265077 1, 2

[4] E. Laviola, M. Gattullo, A. Evangelista, M. Fiorentino, and A. E. Uva. In-situ or side-by-side? A user study on augmented reality maintenance instructions in blind areas. *Computers in Industry*, 144:103795, Jan. 2023. doi: 10.1016/j.compind.2022.103795 1

[5] F. G. W. C. Paas. Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology*, 84(4):429–434, Dec. 1992. doi: 10.1037/0022-0663.84.4.429 1

[6] X. Qiu, Z. Yang, J. Yang, Q. Wang, and D. Wang. Impact of AR Navigation Display Methods on Wayfinding Performance and Spatial Knowledge Acquisition. *International Journal of Human–Computer Interaction*, pp. 1–21, Jan. 2023. doi: 10.1080/10447318.2023.2169524 1

[7] D. Yu, H.-N. Liang, K. Fan, H. Zhang, C. Fleming, and K. Papangelis. Design and Evaluation of Visualization Techniques of Off-Screen and Occluded Targets in Virtual Reality Environments. *IEEE Transactions on Visualization and Computer Graphics*, 26(9):2762–2774, Sept. 2020. doi: 10.1109/TVCG.2019.2905580 1