Defense
Guiding Features in Augmented Reality: A Visual Search Paradigm

Paloma M. Santos

Outline

Background 03

Attention 04

Visual Search 06

Augmented Reality 13

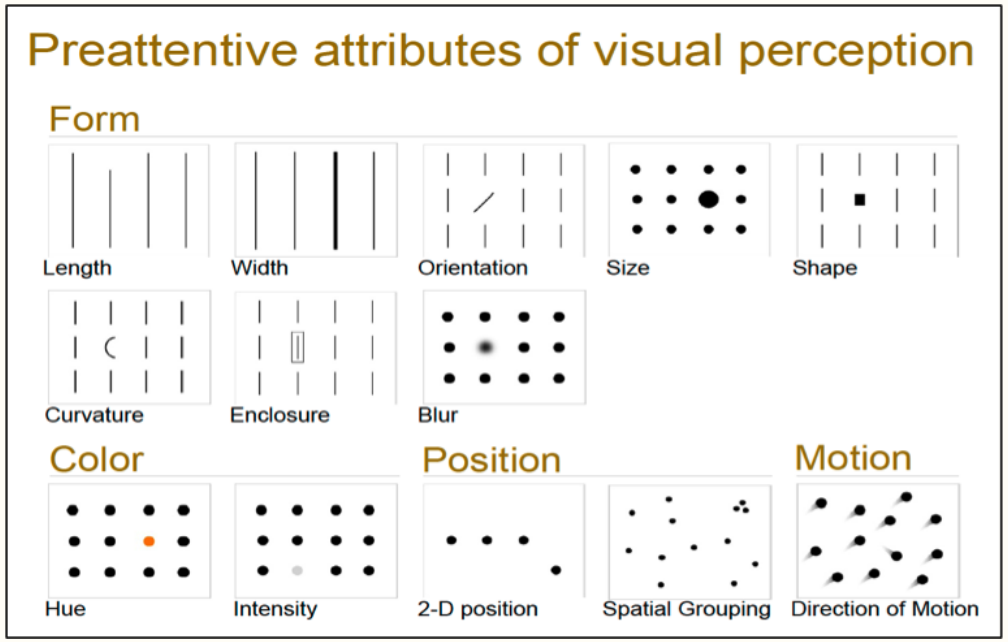
Current Study 16

Results 25

Discussion 30

Attention

Attention: Pre-attentive Processing



- Occurs early in visual processing
- Operates in parallel across the entire visual field
  - Rapidly extracts basic features such as color, forms, position, and motion (Müller & Krummenacher, 2005)
- Mainly automatic (Müller & Krummenacher, 2005)
- Does not require focused attention (Müller & Krummenacher, 2005)

Attention: Attentive Processing

- Binds features into coherent objects
- Pre-attentive and attentive processing bind features to a single representation requiring selective attention (Roskies,1999; Treisman,1996; Wolfe, 2021; Wolfe & Cave,1999)
  - Selective
    - Allows for the prioritization of relevant stimuli (Posner, 1980; Chun et al., 2011)
  - Focused
    - concentration and sustained allocation of cognitive resources on the selected target or task (Posner, 1980; Chun et al., 2011)

Visual Search

Visual Search: Top Down vs. Bottom Up

Simple searches

- Bottom-up salience may be sufficient (Wolfe & Horowitz, 2017)

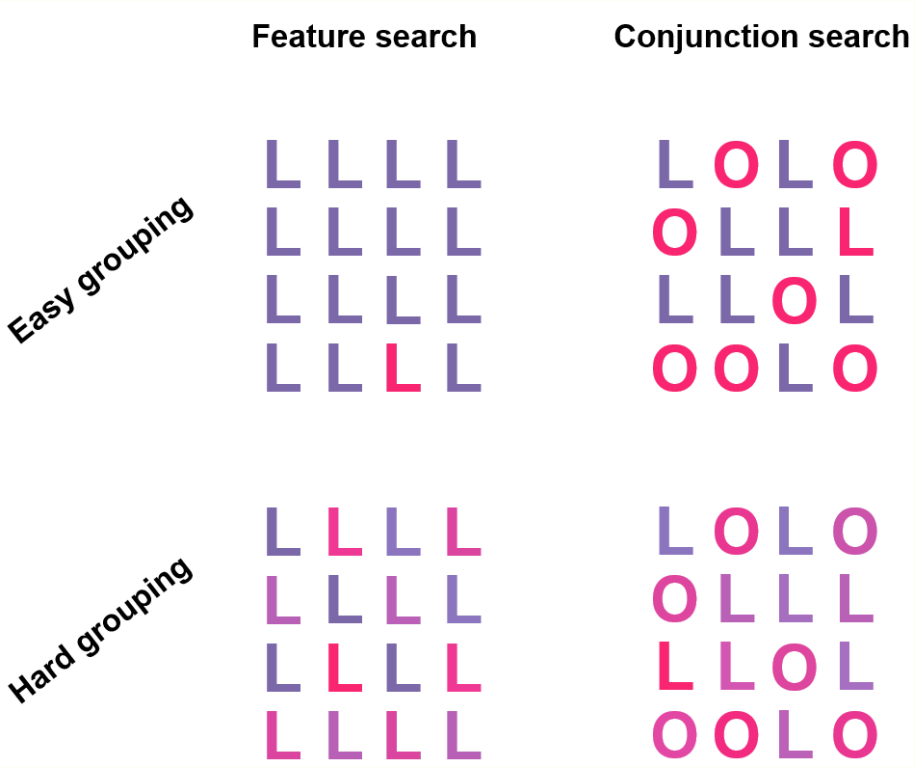


Complex searches

- Greater top-down control required (Wolfe & Horowitz, 2017)



Visual Search: Feature vs Conjunction



- Treisman & Gelade (1980) distinguished between feature and conjunction search
- T and L paradigm
  - Searching for a target letter among distractor letters (Treisman & Gelade, 1980)
- Feature search
  - Efficient, parallel processing, reaction time independent of set size (Treisman & Gelade, 1980; Wolfe, 1994)
- Conjunction search
  - Less efficient, serial processing, reaction time increases with set size (Treisman & Gelade, 1980; Wolfe, 1994)
- Cues can enhance search efficiency by guiding attention to target features (Wolfe, 2021)
  - Color
  - Size
  - Orientation

https://www.hse.ru/en/news/research/416770056.html

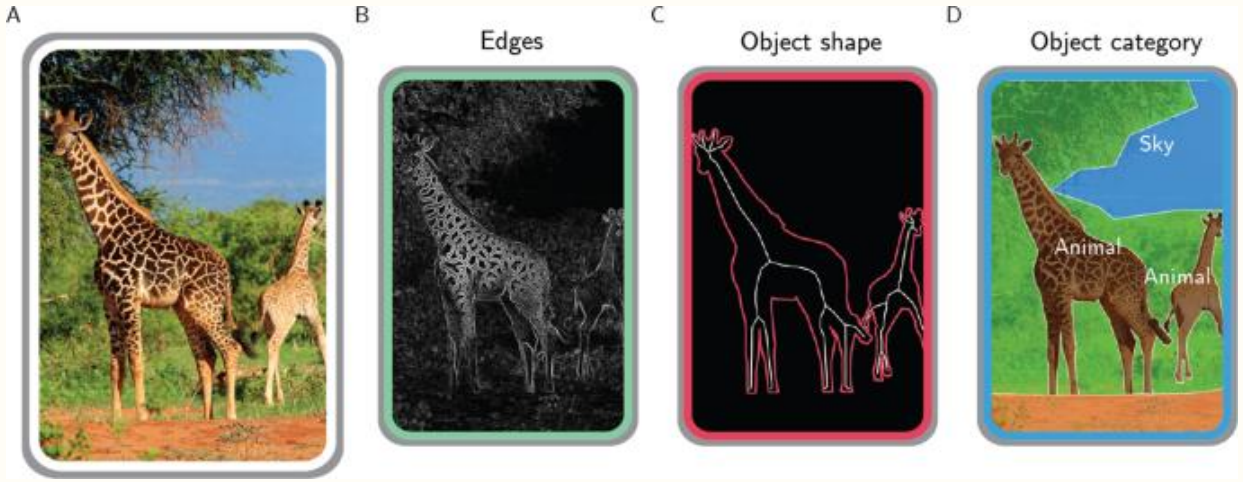
Visual Search: Efficiency of Search

Search array

- The number of items or elements in the visual scene or display that must be searched (Wolfe, 2021)
- ↑ complex search array = ↑ attentional resources
    - Makes it difficult to locate the target stimulus (Wolfe, 2021)
- This complexity is particularly relevant in bottom-up processing, where salient or unexpected stimuli in the environment can capture attention in a data-driven manner (Wolfe, 2021)
- Top down processing can guide attention toward relevant stimuli in the search array (Desimone & Duncan, 19995).



Visual Search: Efficiency of Search



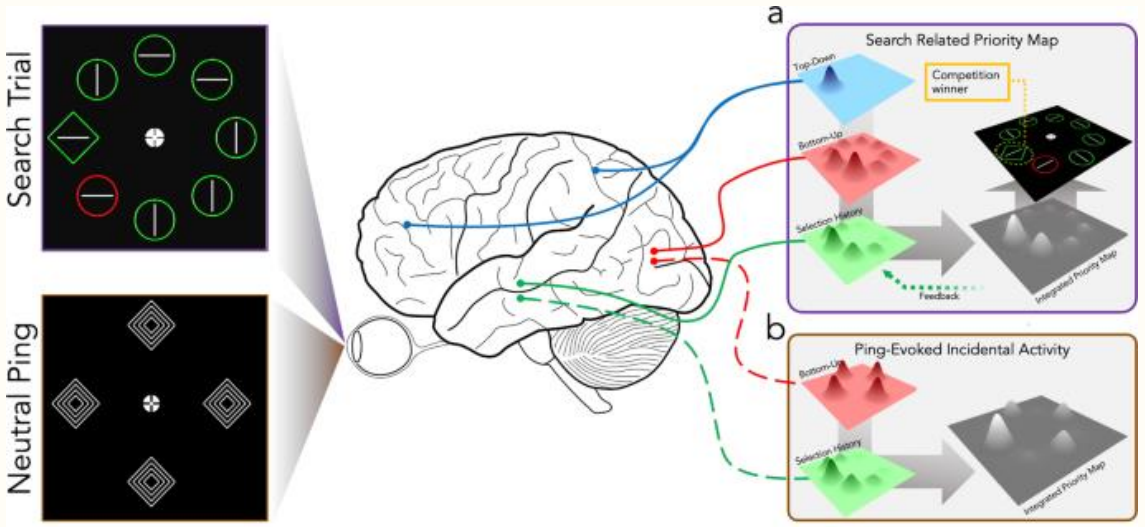
Target template specificity

- The precision and detail of the internal representation or template of the target stimulus that the observer holds in their mind (Olivers et al., 2011)
- Well defined features, facilitates top-down attentional guidance, allowing the observer to selectively attend to stimuli that match the template and ignore irrelevant information (Olivers et al., 2011)

Visual Search: Efficiency of Search

Priority map

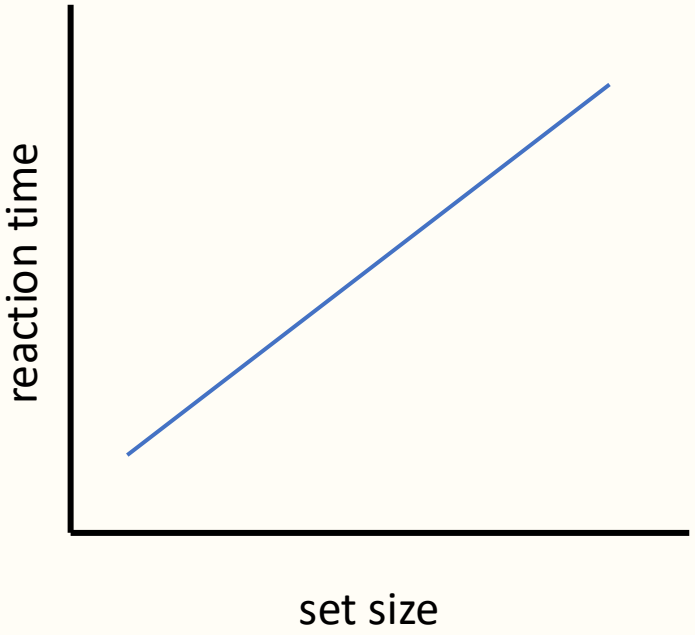
- Theoretical construct representing the overall priority of each location in the visual field (Bisley & Goldberg, 2010; Fecteau & Munoz, 2006)
  - Combines bottom-up salience and top-down relevance
  - Coarse representation of features; fine discriminations require attention (Anderson et al., 2016)
- Factors influencing the priority map (Wolfe, 2021)
  - Salience
  - Observer's goals
  - Learned associations
  - Rewards



Visual Search: Measuring Efficiency

Reaction time

- Widely used to assess visual search efficiency
  - Slope of the RT × set size function serving as an indicator of search efficiency (Palmer et al., 2000)
- Reaction time used to distinguish feature vs. conjunction search (Treisman & Gelade (1980)
- Reaction time increased with set size in conjunction search (Wolfe et al., 1989)
- Guided Search model used reaction time to assess search efficiency (Wolfe, 1994):
- Reaction time used to compare fixation-based and item-based search theories (Hulleman & Olivers, 2017)
- Reaction time used to assess the impact of target-distractor similarity on search performance (Hulleman & Olivers, 2017)



AR Research

AR Studies

Warden et al., 2022





Wieland et al., 2022

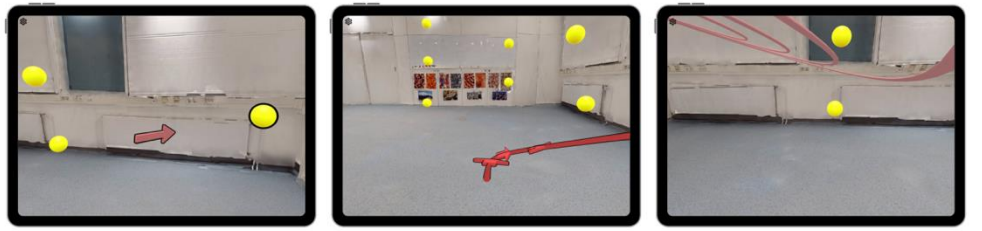


Figure 1: We compared different 3D out-of-view object visualizations for handheld AR displays: A 3D arrow pointing towards the POI *(left)*, a Bézier curve leading to the POI *(middle)*, and pulsing 3D halos starting at the POI's position *(right)*.



Zhao et al., 2016

AR Meta-analyses

Chen et al., 2019	Arena et al., 2022	Dargan et al., 2023

• AR is applied in many fields
• Cloud computing issues
• User experience issues
• Connection issues
• Feature point information issues
	• Rapidly evolving field
	• Interoperability issues
	• Compatibility issues
	• Need for improvements in artificial vision modules
	• Most research done with key words
	  • virtual reality
	  • design
	  • education
		• Designs are overloaded and users often ignore virtual augmented keys
		• Hardware and software issues
		• Limitations in terms of contrast, vision, and resolution
		• Eyestrain issues
		• Navigation techniques are distracting

Current Study

Question of Interest

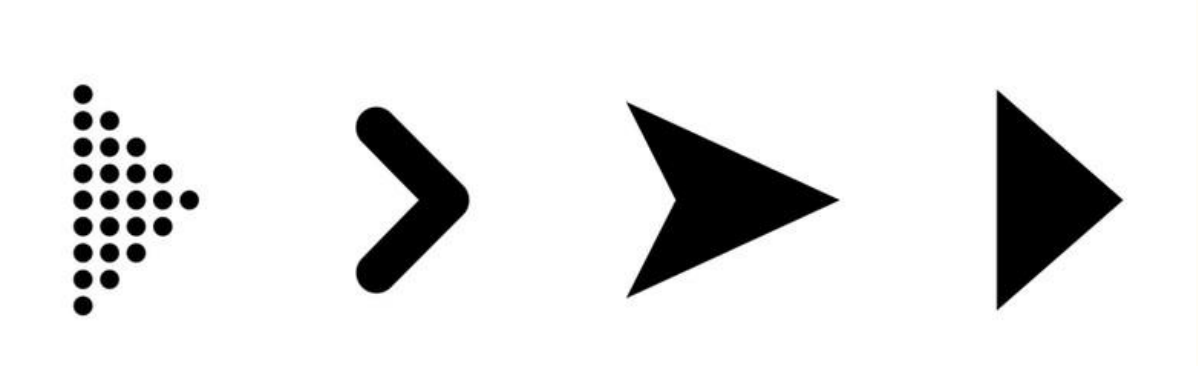
1. How can we design features in augmented reality with a visual science perspective?

2. How can augmented reality facilitate visual search research?

AR Stimuli

Arrow

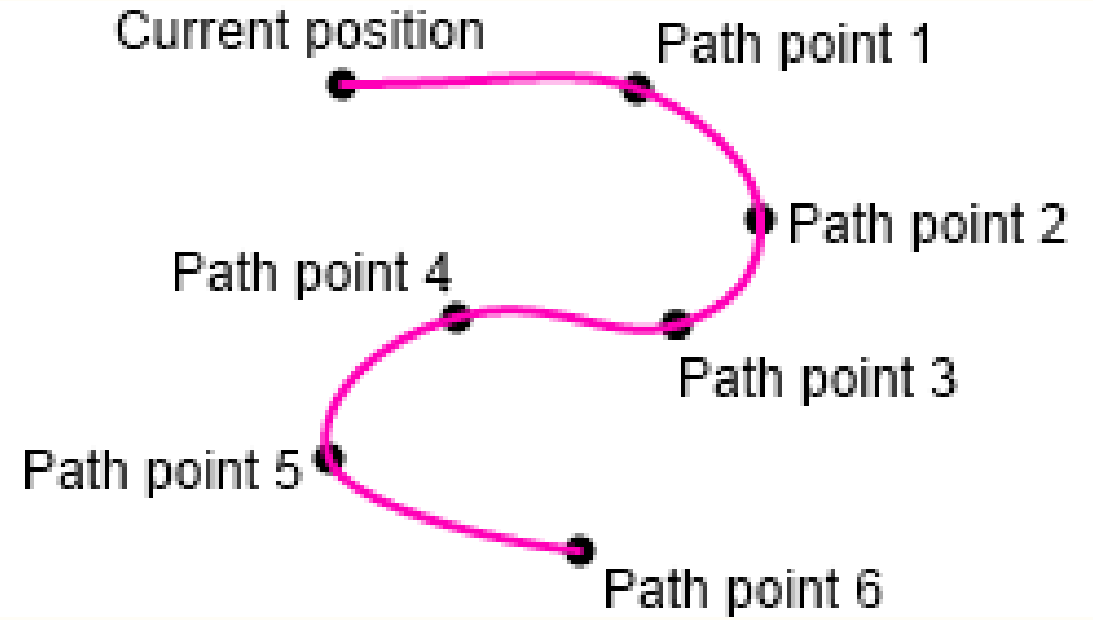
- Represents a more symbolic and conceptual approach to guiding attention
- An explicit directional cue, the arrow taps into users' pre-existing knowledge and expectations about how to navigate and find objects in space
- Previous studies have shown that arrow cues can effectively guide attention and facilitate target detection in a variety of contexts (Weiland et al., 2022;Zhang et al., 2023)



AR Stimuli

Motion spline

- A dynamic, eye-catching path that leads users directly to the target object by following motion towards the object
- Wallgrun et al. (2020) found that path planes, a series of waypoints from the user's location to the target, outperformed 3D arrows and point-of-interest maps
- Research has demonstrated the strong attention-capturing power of motion cues
    - Wolfe proposed motion as a possible low level feature that guides attention (Franconeri & Simons, 2003)



Design

3 x 3 mixed factorial design

- Two IVs
    1. AR Guiding feature (arrow, motion spline, and no cue) and
    2. Task difficulty level defined by number of distractors present (low, medium, and high)
- Two DVs
    1. Search time
    2. Questionnaire responses assessing
        1. Workload (NASA-TLX)
- Two CVs
    1. Cybersickness (ARSQ)
    2. ADHD

Aims and Hypothesis

1. To assess if guiding features in augmented reality lead to faster search time and less workload in the visual search task
    1. Search times will be faster when using augmented reality guiding features (arrow and motion spline) compared to no cue (control), with the motion spline condition showing the shortest time to find the target
    2. Workload will decrease when using augmented reality guiding features (arrow and motion spline) compared to no cue (control)
2. To assess the effects of trial difficulty and guiding features in augmented reality
    1. Search time will be affected by the guiding feature and difficulty level, with the motion spline cue resulting in significantly faster search times than static guiding feature (arrow) for difficult trials
3. To assess if guiding features in augmented reality cause fatigue
    1. Participants in the static guiding cues will exhibit less AR fatigue than those in the non-static conditions

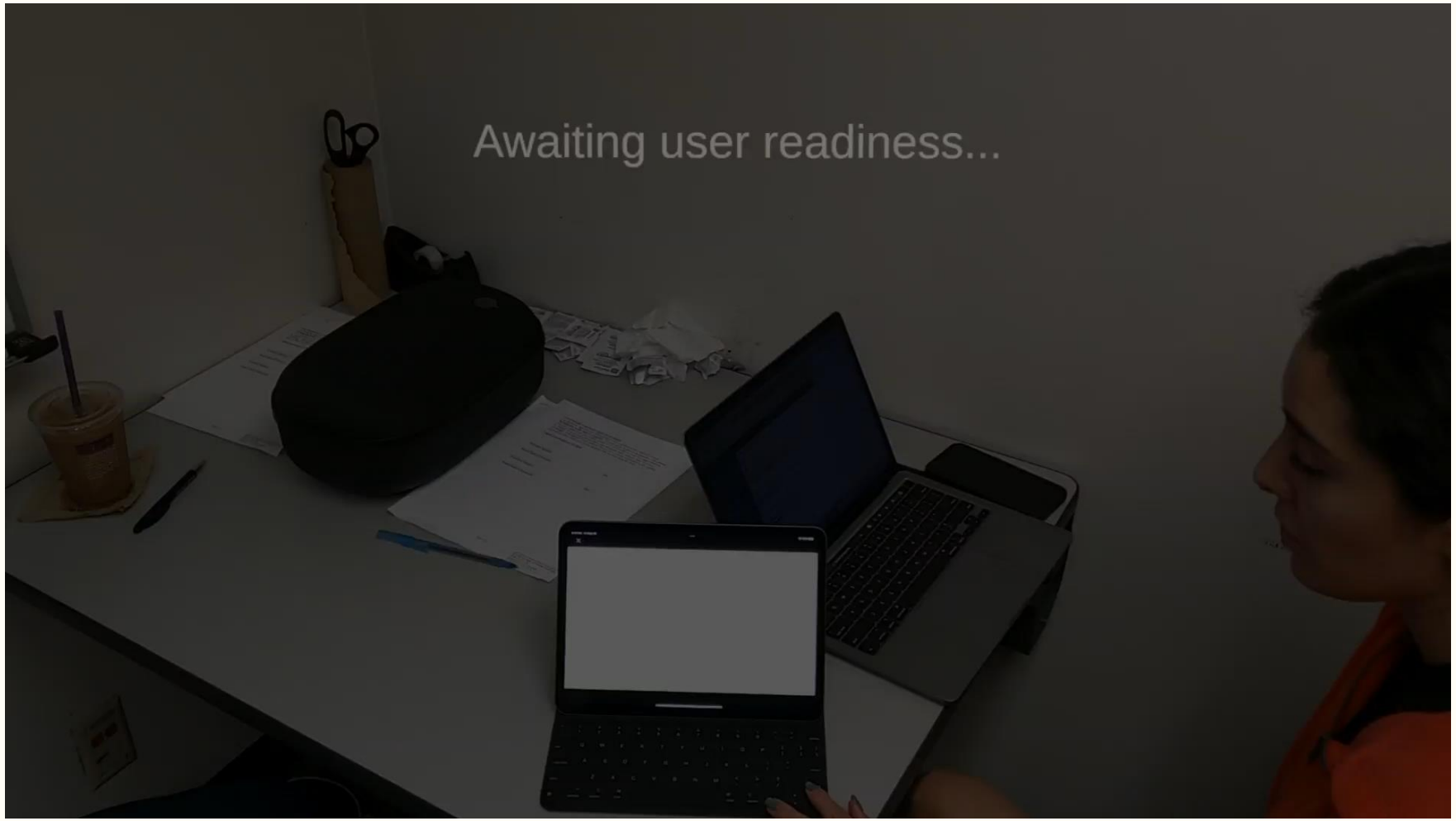
Methods

Participants

- 54 participants selected via SONA
- 18-28 years (*M* = 19.18, *SD* = 1.68)
- 33 females and 18 males



AR Stimuli



Methodology

Procedure

- Participants are screened for eligibility criteria
- Presented with consent form
- Pre training (Motion spline, Arrow, or No Cue)
- Task (Motion spline, Arrow, or No Cue)
- Survey

Results

Results

	ARSQ	Workload	ADHD	Overall Search Time
ARSQ	1	.427	.557	.095
Workload		1	.878	.448
ADHD			1	.859
Overall Search Time				1

	ARSQ	ADHD	Condition
Workload	0.4976	0.7522	0.3060
Overall Search Time	0.0795	0.3784	0.0591

*Note: ***p <.001; **p<.01; *p<.05*

- The overall MANCOVA was not significant, $F(2,46) = 1.95$, $p = .108$. Running the separate ANOVAs for the DVs
- Condition type did not significantly effect workload when controlling for cybersickness (ARSQ) and ADHD, $F(2,46) = 1.2151$, $p = 0.3060$
- Condition type did not significantly effect overall search time when controlling for cybersickness (ARSQ) and ADHD, $F(2,46) = 3.0093$, $p = 0.05913$

Results

	Condition
Workload	0.2612
Overall Search Time	0.0484*

	Difference	*p*
Motion - No cue	-26.38700	0.1796651
Arrow - No cue	10.46393	0.7349018
Arrow - Motion Spline	36.85093	0.0425573*

*Note: ***p <.001; **p<.01; *p<.05*

- The overall MANOVA was not significant, $F(2,49)= 2.07$, $p= 0.090$
- Condition type did not significantly effect workload: $F(2,49) = 1.3798$, $p = 0.2612$
- Condition type significantly effected overall search time, $F(2,49) = 3.2223$, $p = 0.0484$
- Tukey HSD test revealed a significant difference in search time between the arrow and motion spline ($p = .043$), with a difference of 36.85

Results

	Condition	Difficulty	Condition x Difficulty
Search Time	0.689	6.28e-06 ***	0.897

	Difference	*p*
Low - Medium	116.05	<.0001 ***
Low - High	110.06	<.0001 ***
Medium - High	-5.99	0.9669

*Note: ***p <.001; **p<.01; *p<.05*

- Condition type did not effect search time, $F(1,147) = 0.161$, $p = .689$
- Difficulty level did have a significant effect on search time, $F(2,147) = 13.010$, $p < .001$
- No significant interaction between condition and difficulty level on search time, $F(2,147) = 0.109$, $p = .897$.
- A significant difference in the search time between
  - Low difficulty level and medium difficulty level ($p < .0001$)
  - Low difficulty level and high difficulty level ($p < .0001$)
- No significant difference between the medium and high difficulty levels ($p = .9669$)

Results

	t	*p*
concodes	-.0299	0.766

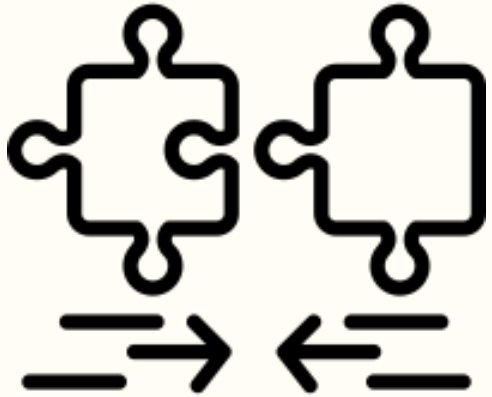
*Note: ***p <.001; **p<.01; *p<.05*

- The regression analysis revealed that the predictor variable "concodes" was not statistically significant $p = 0.766$



Discussion

Implications



Hypothesis 1

- Motion spline outperformed arrow cue in search time
  - No significant difference between motion spline and no cue
- Motion as a low-level feature may guide attention effectively
- Importance of cue design and task complexity in AR visual search

Hypothesis 2

- Difficulty levels affect search time, but not as expected
- Potential priming effect in medium and high-difficulty trials
- Need for better isolation of difficulty levels in experimental design
- Importance of considering visual science principles in AR research

Hypothesis 3

- No significant difference in cybersickness between conditions
- Motion spline shows promise for efficient, non-obtrusive guidance
- Potential for developing user-friendly AR guidance systems

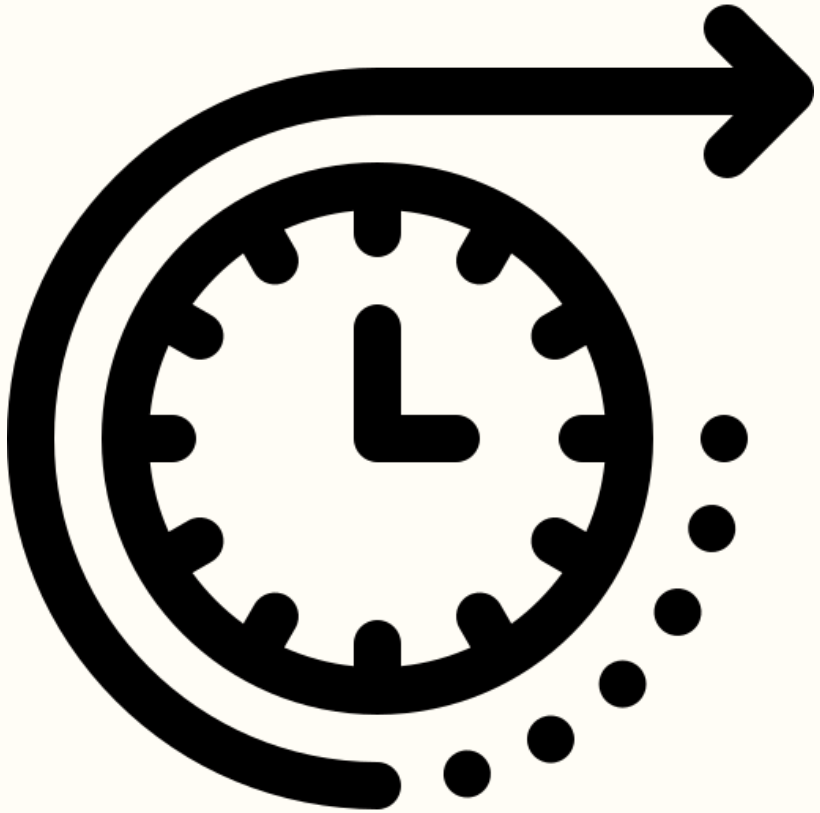
Limitations and Alternative Explanations



- Sample Size and Variability
- Participant Motivation
- Technical Issues
- Experimental Design Considerations
- Further Research Needed

Future Directions

- Enhanced Experimental Setup
- Improved Instructions
- Expanded Guiding Cue Evaluation
- Gaze Pattern Analysis
- Color Priming Investigation
- Attention Process Isolation
- AR Interface Development
- Broader Applications and Implications



References

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Anderson, N. C., Donk, M., & Meeter, M. (2016). The influence of a scene preview on eye movement behavior in natural scenes. *Psychonomic Bulletin & Review*, *23*, 1794-1801.

Arena, F., Collotta, M., Pau, G., & Termine, F. (2022). An overview of augmented reality. Computers, 11(2), 28.

Arevalo Arboleda, S., Rücker, F., Dierks, T., & Gerken, J. (2021, May). Assisting manipulation and grasping in robot teleoperation with augmented reality visual cues. In Proceedings of the 2021 CHI conference on human factors in computing systems (pp. 1-14).

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational research review*, *20*, 1-11.

Castelhano, M. S., & Witherspoon, R. L. (2016). How you use it matters: Object function guides attention during visual search in scenes. *Psychological Science*, *27*(5), 606-621.

Chen, X., & Zelinsky, G. J. (2006). Real-world visual search is dominated by top-down guidance. Vision Research, 46(24), 4118-4133. doi:10.1016/j.visres.2006.08.008.

Cheng, K. H., & Tsai, C. C. (2013). Affordances of augmented reality in science learning: Suggestions for future research. Journal of science education and technology, 22, 449 462.

Chun, M. M. (2011). Visual working memory as visual attention sustained internally over time. Neuropsychologia, 49(6), 1407-1409.

Clarke, D. D., & Sokoloff, L. (1994). Circulation and energy metabolism of the brain. Basic neurochemistry: molecular, cellular and medical aspects. ed, 6.

Contreras, P., Chimbo, D., Tello, A., & Espinoza, M. (2017, September). Semantic web and augmented reality for searching people, events and points of interest within of a university campus. In 2017 XLIII Latin American Computer Conference (CLEI) (pp. 1 10). IEEE.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. Nature Reviews Neuroscience, 3(3), 201-215. https://doi.org/10.1038/nrn755

Dargan, S., Bansal, S., Kumar, M., Mittal, A., & Kumar, K. (2023). Augmented reality: A comprehensive review. Archives of Computational Methods in Engineering, 30(2), 1057 1080.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. Annual Review of Neuroscience, 18(1), 193-222. https://doi.org/10.1146/annurev.ne.18.030195.001205

Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. *Handbook of research on educational communications and technology*, 735-745.

Ehinger, K. A., & Wolfe, J. M. (2016). When is it time to move to the next map? Optimal foraging in guided visual search. Attention, Perception, & Psychophysics, 78, 2135-2151.

Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. & psychophysics, 65(7), 999-1010.

Goddard, K., Roudsari, A., & Wyatt, J. C. (2012). Automation bias: a systematic review of frequency, effect mediators, and mitigators. Journal of the American Medical Informatics Association, 19(1), 121-127.

Grieben, R., Tekülve, J., Zibner, S. K., Lins, J., Schneegans, S., & Schöner, G. (2020). Scene memory and spatial inhibition in visual search: A neural dynamic process model and new experimental evidence. *Attention, Perception, & Psychophysics*, *82*, 775-798.

Hammady, R., Ma, M., Strathern, C., & Mohamad, M. (2020). Design and development of a spatial mixed reality touring guide to the Egyptian museum. Multimedia Tools and Applications, 79, 3465-3494.

Hertenstein, J. H., Platt, M. B., & Veryzer, R. W. (2013). What is "Good Design"?: an investigation of the complexity and structure of design. *Design Management Journal*, *8*(1), 8-21.

Hou, L., Wang, X., Bernold, L., & Love, P. E. (2013). Using animated augmented reality to cognitively guide assembly. Journal of Computing in Civil Engineering, 27(5), 439-451.

Hulleman, J., & Olivers, C. N. (2017). The impending demise of the item in visualsearch. *Behavioral and Brain Sciences*, *40*, e132. James, W. (1890). The Principles of Psychology. Henry Holt and Company.

Koehler, K., Guo, F., Zhang, S., & Eckstein, M. P. (2014). What do saliency models predict?. *Journal of vision*, *14*(3), 14-14.

Le Chénéchal, M., Duval, T., Gouranton, V., Royan, J., & Arnaldi, B. (2019). Help! i need a remote guide in my mixed reality collaborative environment. *Frontiers in Robotics and AI*, *6*, 106.

Li, K., Kadohisa, M., Kusunoki, M., Duncan, J., Bundesen, C., & Ditlevsen, S. (2020). Distinguishing between parallel and serial processing in visual attention from neurobiological data. Royal Society Open Science, 7(1), 191553.

Lu, W., Duh, H. B. L., Feiner, S., & Zhao, Q. (2013). Attributes of subtle cues for facilitating visual search in augmented reality. *IEEE transactions on visualization and computer graphics*, *20*(3), 404-412.

Lu, Y., Zhao, M., Han, T., Yao, X., Lin, S., Xu, F., ... & Chen, Y. (2013). Enhancing visual search in augmented reality using subtle gaze direction. In Proceedings of the adjunct publication of the 26th annual ACM symposium on User interface software and technology (pp. 3-8). https://doi.org/10.1145/2508468.2514721

Mehalik, M., & Schunn, C. (2007). What constitutes good design? A review of empirical studies of design processes. International Journal of Engineering Education, 22(3), 519.

Mullane, J. C., & Klein, R. M. (2008). Literature review: Visual search by children with and without ADHD. Journal of Attention Disorders, 12(1), 44-53. https://doi.org/10.1177/1087054707305116

References

Mulloni, A., Seichter, H., & Schmalstieg, D. (2011, October). User experiences with augmented reality aided navigation on phones. In 2011 10th IEEE international symposium on mixed and augmented reality (pp. 229-230). IEEE.

Niebur, E., & Koch, C. (1995). Control of selective visual attention: Modeling the" where" pathway. *Advances in neural information processing systems*, *8*.

Olivers, C. N., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states of visual attention: Evidence from the N2pc and P3. Journal of Cognitive Neuroscience, 23(2), 421-438. https://doi.org/10.1162/jocn.2009.21352

Oh, B. I., Kim, Y. J., & Kang, M. S. (2019). Ensemble representations reveal distinct neural coding of visual working memory. Nature communications, 10(1), 5665.

Olk, B., Dinu, A., Zielinski, D. J., & Kopper, R. (2018). Measuring visual search and distraction in immersive virtual reality. *Royal Society open science*, *5*(5), 172331.

Palmer, J., Verghese, P., & Pavel, M. (2000). The psychophysics of visual search. Vision Research, 40, 1227-1268. doi:10.1016/S0042-6989(99)00244-8.

Posner, M. I. (2022). Current research in the study of selective attention. Cognitive psychophysiology: Event-related potentials and the study of cognition, 37-50.

Rafiq, A., & Ahsan, B. (2014). Secure and dynamic model for book searching on cloud computing as mobile augmented reality. International Journal of Modern Education and Computer Science, 6(1), 72.

Ruth Rosenholtz, Yuanzhen Li, Jonathan Mansfield, and Zhenlan Jin. 2005. Feature congestion: a measure of display clutter. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '05). Association for Computing Machinery, New York, NY, USA, 761–770. https://doi.org/10.1145/1054972.1055078

Rosenholtz, R., Li, Y., & Nakano, L. (2007). Measuring visual clutter. Journal of Vision, 7(2), 17 17. https://doi.org/10.1167/7.2.17

Rosenholtz, R. (2001). Search asymmetries? What search asymmetries?. *Perception & Psychophysics*, *63*, 476-489.

Roskies, A. L. (1999). The binding problem. Neuron, 24(1), 7-9.

Santos, M. E. C., Chen, A., Taketomi, T., Yamamoto, G., Miyazaki, J., & Kato, H. (2013). Augmented reality learning experiences: Survey of prototype design and evaluation. *IEEE Transactions on learning technologies*, *7*(1), 38-56.

Shen, J; Reingold, EM; Pomplun, M (June 2003). "Guidance of eye movements during conjunctive visual search: the distractor-ratio effect". Canadian Journal of Experimental Psychology. 57 (2): 76–96. CiteSeerX 10.1.1.59.251. doi:10.1037/h0087415. PMID 12822838.

Tatler, B. W., Hayhoe, M. M., Land, M. F., & Ballard, D. H. (2011). Eye guidance in natural vision: Reinterpreting salience. Journal of Vision, 11(5). https://doi.org/10.1167/11.5.5

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. Acta Psychologica, 135(2), 77-99. https://doi.org/10.1016/j.actpsy.2010.02.006

Torralba, A., Oliva, A., Castelhano, M. S., & Henderson, J. M. (2006). Contextual guidance of eye movements and attention in real-world scenes: the role of global features in object search. *Psychological review*, *113*(4), 766.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. Cognitive Psychology, 12(1), 97-136. https://doi.org/10.1016/0010-0285(80)90005-5

Treisman, A., & Sato, S. (1990). Conjunction search revisited. *Journal of experimental psychology: human perception and performance*, *16*(3), 459.

Trepkowski, C., Eibich, D., Maiero, J., Marquardt, A., Kruijff, E., & Feiner, S. (2019, March). The effect of narrow field of view and information density on visual search performance in augmented reality. In 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR) (pp. 575-584). IEEE.

Võ, M. L. H., & Wolfe, J. M. (2013). Differential electrophysiological signatures of semantic and syntactic scene processing. Psychological science, 24(9), 1816-1823.

Wallgrün, J. O., Bagher, M. M., Sajjadi, P., & Klippel, A. (2020, March). A comparison of visual attention guiding approaches for 360 image-based vr tours. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 83-91). IEEE.

Warden, A. C., Wickens, C. D., Mifsud, D., Ourada, S., Clegg, B. A., & Ortega, F. R. (2022). Visual Search in Augmented Reality: Effect of Target Cue Type and Location. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 66(1), 373 377. https://doi.org/10.1177/1071181322661260

Wieland, J., Garcia, R. C. H., Reiterer, H., & Feuchtner, T. (2022, October). Arrow, bézier curve, or halos?–Comparing 3D out-of-view object visualization techniques for handheld augmented reality. In 2022 IEEE International Symposium on Mixed and Augmented Reality (ISMAR) (pp. 797-806). IEEE.

Wolf, D., Besserer, D., Sejunaite, K., Riepe, M., & Rukzio, E. (2018, October). care: An augmented reality support system for dementia patients. In *Adjunct Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (pp. 42-44).

Wolfe, J. M. (1994). Guided search 2.0 a revised model of visual search. Psychonomic bulletin& review, 1, 202-238.

Wolfe, J. M. (2020). Visual search: How do we find what we are looking for?. *Annual review ofvision science*, *6*, 539-562.

Wolfe, J. M. (2021). Guided Search 6.0: An updated model of visual search. Psychonomic Bulletin & Review, 28(4), 1060-1092. https://doi.org/10.3758/s13423-020-01859-9

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: an alternative to the feature integration model for visual search. Journal of Experimental Psychology: Human perception and performance, 15(3), 419.

Wolfe, J. M., & Gray, W. (2007). Guided search 4.0. Integrated models of cognitive systems, 99119.

Wolfe, J. M., & Horowitz, T. S. (2017). Five factors that guide attention in visual search. Nature Human Behaviour, 1(3), 0058. https://doi.org/10.1038/s41562-017-0058

Woodman, G. F., & Luck, S. J. (1999). Electrophysiological measurement of rapid shifts of attention during visual search. Nature, 400(6747), 867-869.https://doi.org/10.1038/23698

Wolford, G., & Chambers, L. (1983). Lateral masking as a function of spacing. Perception & Psychophysics, 33, 129-138.

Yamauchi, K., & Kawahara, J. I. (2020). Inhibitory template for visual marking with endogenous spatial cueing. Visual Cognition, 28(10), 581-604.

Zahiri, M., Nelson, C. A., Oleynikov, D., & Siu, K. C. (2018). Evaluation of augmented reality feedback in surgical training environment. Surgical Innovation, 25(1), 81-87.

Zhang, T., Gao, Y., Hu, S., Xiong, L., Cheng, Z., Tian, Y., ... & Wang, Y. (2023). Focused attention: its key role in gaze and arrow cues for determining where attention is directed. Psychological research, 87(6), 1966-1980.

Zhang, Y., Nowak, A., Xuan, Y., Romanowski, A., & Fjeld, M. (2023, October). See or Hear? Exploring the Effect of Visual/Audio Hints and Gaze-assisted Instant Post-task Feedback for Visual Search Tasks in AR. In *2023 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 1113-1122). IEEE.

THANK YOU!

Questions?

Sample Size

Sample Size



Figure 1. Depiction of the search environment. The objects shown here are slightly more complex than those used in the actual experiment and were used in a later experiment which provided equivalent results.

Shown in Figure 2, the arrow cue was a 2D AR arrow depicted in world-referenced coordinates and pointed in the direction of the target until that target was located. The icon cue was an image of the target object displayed in screen-referenced coordinates and was continuously visible at a fixed location on the HMD as the participant looked for the objects within a 180-degree visual field. The minimap cue, depicted in screen-referenced coordinates, was a 360 degree top-down depiction of the location of all the possible objects in the far domain with the target object highlighted on the map.



Figure 2. Example images of the arrow, icon, and minimap cue, respectively. The box surrounding the object appears when the participant fixates on the object. In the center image, the icon representation of the target is on the right.

Target cues were presented either at the central field of view (referred to as the 'center' location) or approximately 15 degrees downward from the center (referred to as the 'down' location) on the AR-HMD.

Design

All participants completed eight practice trials (2 for each cueing condition) where they received correct or

condition and cue location were randomized in terms of target location. For the no cue condition, participants completed two sets of 4 trials that were included in the cue condition counterbalancing previously described. The entire experiment consisted of 40 trials and lasted approximately 30 minutes.

Procedure

All participants gave informed consent before they began the experiment. Participants completed a pre-calibration process with the Hololens 2, ensuring accurate eye-gaze detection. Participants read instructions about the visual search task and were told to make their responses as rapidly and accurately as possible. Participants were told to look at a designated mark on the wall at the beginning of the experiment and to return to this location at the beginning of each trial.

RESULTS

Data from one participant was excluded from the analysis because that participant had chance performance. Data were analyzed in R using one-way repeated measures ANOVAs to examine the effect of target cue conditions (arrow, minimap, icon, no cue) on response time and percent error. Next, we conducted a 3 (target cues) x 2 (location) repeated measures ANOVA to examine the effect of location and its interaction with target cue type. All response time data were log-transformed because the data were positively skewed.

Effect of Target Cue Conditions

Response Time. Figure 3 presents the mean response time for each type of target cue, including the no cue condition. The assumption of sphericity was violated for response time data; therefore, we report the p-value of the Greenhouse-Geisser correction for the ANOVA. An ANOVA showed a large effect of cue type on the log-transformed response time, $F(3, 69) = 17.8$, $p < .001$, $\eta_p^2 = 0.44$. Participants located the object faster when using a cue compared to no cue (rightmost bar). Pairwise t-test revealed that participants found the target object significantly faster when using the arrow cue ($M = 4.87$ s) compared to the no cue condition ($M = 10.2$ s, $t(23) = -5.52$, $p < .001$, $d = 1.28$), icon cue ($M = 9.21$ s, $t(23) = -7.18$, $p < .001$, $d = 1.53$), and minimap cue ($M = 6.67$ s, $t(23) = -2.91$, $p < .008$, $d = 0.53$). They were also faster using the minimap cue compared to the no cue condition ($t(23) = 2.96$, $p = .007$, $d = 0.82$) and to the icon cue ($t(23) = 4.60$, $p < .001$, $d = 0.96$).

Copyright 2022 by Human Factors and Ergonomics Society. All rights reserved. 10.1177/10711181322661260

