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Place in the World or Place on the Screen? Investigating the Effects of Augmented Reality Head-Up Display User Interfaces on Drivers' Spatial Knowledge Acquisition and Glance Behavior

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Abstract

When navigating via car, developing robust mental representations (spatial knowledge) of the environment is crucial in situations where technology fails, or we need to find locations not included in a navigation system's database. In this work, we present a study that examines how screen-relative and world-relative augmented reality (AR) head-up display interfaces affect drivers' glance behavior and spatial knowledge acquisition. Results showed that both AR interfaces have similar impact on the levels of spatial knowledge acquired. However, eye-tracking analyses showed fundamental differences in the way participants visually interacted with different AR interfaces; with conformal-graphics demanding more visual attention from drivers.

Keywords: Augmented Reality, Head-Up Display, Spatial Knowledge, Driving.

Index Terms: H.5.1: Multimedia Information Systems — Artificial, Augmented, and Virtual Realities; H.5.2: User Interfaces — Ergonomics, Evaluation / Methodology, Screen Design, Style Guides

1 Introduction and Related Work

Finding our way through new driving environments has considerably changed in the past decades. We evolved from navigating by using a collection of fold-out paper maps to using in-vehicle navigation systems (termed SatNav). Regardless of the potential opportunities that SatNavs provide, their use can also be problematic. For example, research suggests that drivers using SatNav do not develop as much robust environmental spatial knowledge as drivers using paper maps [1, 2].

Augmented reality (AR) head-up displays (HUDs) provide new opportunities to display navigation information directly on the windshield within drivers' forward field of view, allowing drivers to gather information needed to navigate without looking away from the road [3]. To date, the vast majority of driving studies investigating spatial knowledge acquisition have employed head-down displays, typically located in the center of the vehicle dashboard. However, AR HUDs allow designers to overlay navigation information directly onto real-world landmarks, thus allowing drivers to potentially acquire greater spatial knowledge as compared to head-down display navigation systems [4].

While AR HUDs are promising, the nuances of visual interface design and its impacts on drivers must be further understood before AR can be widely and safely incorporated into vehicles. Specifically, most current HUD technologies have limited field of view (6-15 degrees), and a single fixed focal plane. Even though the human foveal vision makes up about 1° of the visual field, we depend heavily on peripheral vision for visual driving tasks, and thus, a limited AR HUD FOV can make driving more difficult because important road elements and environmental landmarks might lie outside the AR interface (which makes presenting conformal graphics in these locations impossible without improvements in AR HUD technologies). Therefore, in this work we want to understand whether providing conformal AR navigational cues improves spatial knowledge acquisition to the extent that investment in generating larger FOV AR HUDs with potentially multiple focal planes is justifiable. Specifically, we want to answer: *How do HUD graphics' perceptual form (world-relative vs. screen-relative) impact drivers' acquisition of spatial knowledge?*

2 Methods

2.1 Experimental Design and Equipment

We employed a 2x2 between-subject experimental design with the following independent variables: *perceptual form* (world-relative arrow (Figure 1) and, screen-relative (Figure 2)), and *gender* (female and male). We recruited twenty-four participants (twelve males and twelve females) aged between 18-40 years for this study. All participants had a valid driver's license and had normal or corrected-to-normal vision.

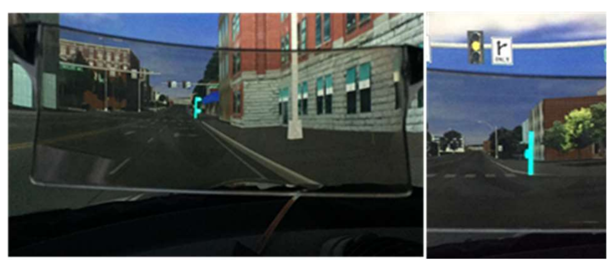

Figure 1: World-relative straight arrow post sign at distance for right turn (left) and approaching the straight turn (right).

Figure 2: Screen-relative traditional arrow for straight turn (right) and right turn (left).

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2.2 Equipment

A fixed-base, medium fidelity driving simulator was used for this study. This simulator is composed of the front half of a 2014 Mini Cooper cab fitted with a curved projection with 94 degrees of view displaying a simulated road scene and contains both side and rear-view mirrors that allow participants to view their surroundings. Additionally, the simulator is equipped with a Pioneer Cyber Navi HUD with conformal AR graphics capabilities. The area displayed on HUD is 780x260 pixels, FOV is 15 degrees and the virtual image position is approximately 3m away from the eyepoint. During the study, participants wore SensoMotoric Instruments (SMI) eye-tracking glasses equipped with audio and video recording.

2.3 Procedures

Upon arriving to the lab, participants completed a short demographic survey and consented to the research. We instructed them to perform a familiarization drive (five minutes) to get comfortable with both car dynamics and driving simulator functionalities. Participants were randomly assigned either the world-fixed or screen-fixed condition and were unaware of which condition was being applied to them during the study. Each data collection drive lasted between 10 and 15 minutes. During this drive, participants drove through a route and were encouraged to verbally share feedback as they proceeded. The researchers did not provide any driving feedback unless participants missed a turn. After the drive, individuals filled out an open feedback survey and a NASA-TLX questionnaire to record their perceived workload. Following the completion of questionnaires, participants were led to a new room in which they were asked to complete a landmark and route knowledge test. We assessed landmark knowledge using an iconic recognition task, which involves the correct identification of a target image of specific landmarks encountered during the data collection drive. Next, we assessed participants' route knowledge using a scene ordering task, which required participants to sort a set of images into the order they appeared during the data collection drive. After completion of the study, individuals signed a post-trial consent form and were compensated $10 for their time

3 Results

For the landmark test, we found no meaningful differences in the number of scenes correctly sorted across AR interfaces (t (20) =-0.37; p<0.714), and, no meaningful differences in terms of landmark acquisition rate (screen-relative condition 49.49% and world-relative condition, 47.92%; t (20) =0.37; p<0.714). Using signal detection theory (SDT) approach, we calculated sensitivity and bias, and, we found that sensitivity is small, and bias stayed relatively neutral. Also, deviance analysis shows that only maneuver direction had an influence on landmark knowledge testing performance. Regarding the route knowledge test, a two sample un-paired t-test revealed no significant differences in proportion of scenes recalled in the correct order location (t=-1.17; p<0.256) across screen-relative and world-relative conditions.

Regarding the mean glance duration towards different AOIs, we found a main effect of condition on the mean glance duration for the HUD *(p<0.036),* around HUD *(p<0.036)* and close right landmark *(p<0.030).* For these significant results, participants glanced longer towards these AOIs under the world-relative condition than the screen-relative condition. Also, we found that mean HUD graphic glance duration for all participants tended to decrease for both conditions for all 12 scenario events as simulation time passed. Screen–relative condition showed steadier decrease in average duration compared to the world-relative condition. Regarding the number of glances towards different AOIs, results show that the total number of glances directly at both the HUD graphic and around the HUD was higher for the screen-relative condition than the world-relative condition. However, a main effect of condition was only found for the around HUD graphic.

4 Discussion/conclusions

This study paints an initial picture of spatial knowledge acquisition, gaze behavior, and drivers' preferences when designing for in-vehicle HUDs. Two different types of navigation cues were compared: world-relative and screen-relative. We expected that by placing AR cues on the right side of the road, attention would be drawn to right side features of the environment and therefore, participants would remember seeing these landmarks along the drive. In fact, glance behavior results showed that the distribution of visual attention allocation was that the world-relative condition was associated to glances of long duration directed to the right side of the HUD. However, in this study participants using both AR HUDs' perceptual form interfaces presented similar levels of spatial knowledge acquisition. One of the reasons that this may have happened is due to the fact that the world-relative condition AR graphic was not compatible with drivers' mental model of what a navigation cue looks like. Many participants stated not knowing that the "blue markings" were the navigation cues, or they thought there was a pole or a blue 'F' on the side of the road. Therefore, participants glanced longer to the right side of the interface as they were trying to understand what information the system was transmitting to them. As participants learned how the system works, average glance duration decreased, and they were more comfortable using navigation cues. Even though our initial assumption that the conformal AR HUD interface would draw drivers' attention to a specific part of the display was correct, this type of interface was not helpful to increase spatial knowledge acquisition. This finding contrasts a common perspective in the AR community that conformal, world-relative graphics are inherently more effective. We suggest that simple, screen-fixed designs may indeed be effective in certain contexts. Also, we showed that the distribution of visual attention allocation was that the world-relative condition was typically associated with fewer glances in total, but glances of longer duration. Optimal AR graphics would require few glances of short duration in the direction of the graphic and would increase the amount of visual attention available for drivers to allocate to other areas with potential hazards and other driving-relevant information. And as mentioned, this finding alone warrants further investigation since changes in visual attention in more dynamic and dangerous settings can have significant differences in primary task performance (e.g., driving).

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References

[1] W. Waters and S. Winter, "A wayfinding aid to increase navigator independence," *Journal of Spatial Information Science,* pp. 103-122, 2011.

[2] G. Burnett and K. Lee, "The Effect of Vehicle Navigation Systems on the Formation of Cognitive Maps," in *Traffic and Transport Psychology: Theory and Application*, Elsevier, 2005, pp. 407-418.

[3] D. Beck and W. Park , "Perceived Importance of Automotive HUD Information Items: a Study With Experienced HUD Users," *EEE Access,* vol. 6, pp. 21901-21909, 2018.

[4] A. Bolton, G. Burnett and D. Large, "An investigation of Augmented Reality Presentations of Landmark-Based Navigation using Head-Up Display," in *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, Nottingham, United Kingdom, 2015.