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Augmented Reality HUDs: Warning Signs and Drivers' Situation Awareness

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Department of Psychology, College of Liberal Arts
Rochester Institute of Technology

Augmented Reality HUDs: Warning Signs and Drivers' Situation Awareness

by
Zachary McDonald

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Experimental Psychology
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We approve the thesis of Zachary McDonald

Date

Andrew Herbert, Ph.D.

Professor/Department Chair, Dept. of Psychology, RIT

Date

Joseph Baschnagel, Ph.D.

Associate Professor, Dept. of Psychology, RIT

Date

Martin Gordon, PE

Professor, Dept. of Manufacturing & Mechanical Engineering Technology, RIT

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Abstract

Drivers must search dynamic and complex visual environments to perceive relevant environmental elements such as warning signs, pedestrians and other vehicles to select the appropriate driving maneuver. The objective of this research was to examine how an Augmented Reality Head Up Display (AR HUD) for warning signs affects driver Situation Awareness (SA) and attention. Participants viewed videos of real driving scenes with an AR HUDs or no display and were asked to report what elements in the driving scene attracted their attention. At the completion of the first driving video participants were given a warning sign recognition test. Participants then watched a second video and the Situation Awareness Global Assessment Technique (SAGAT), a measure of global SA was administered. Participants eye movements were recorded when watching the videos to investigate how drivers interacting with an AR HUD attend to the environment compared to drivers with no AR HUD. AR HUDs for warning signs are effective in making warning signs more attentionally conspicuous to drivers in both low and high clutter driving environments. The HUD did not lead to increased fixation duration or frequency to warning signs in many situations. However when two driving items were in sight (sign and car) and participants needed to decide where to attend, they experienced attentional tunneling. In complex driving situations participants spent a significantly longer proportion of time looking at warning signs in the HUD. In simple driving situations, AR HUDs appear to make warning signs more salient and conspicuous. However, in complex situations in high clutter driving environments AR HUDs may lead to attentional tunneling.

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Augmented Reality HUD Warning Signs and Drivers' Situation Awareness

Conducting a successful and efficient visual search of the environment is necessary for many tasks. The dynamic and complex environments encountered when driving a vehicle can place heavy demands on drivers who at times may fail to detect and perceive relevant stimuli. Failures in driver attention and inefficient visual search strategies are responsible for many traffic accidents and this will continue to if measures are not taken to reduce the attentional and visual demands on drivers. Singh (2015) studied a weighted sample of 5,470 traffic accidents (which represented 2,189,000 traffic accidents in the United States between 2005 and 2007) to determine the main contributing factors for accidents. Singh (2015) reported that 95% of all crashes could be attributed to driver error; classified as recognition error, decision error, performance error, non-performance error (e.g. lack of sleep) or other miscellaneous factors. By extrapolation, this suggests approximately 75% (1.5 million) of crashes related to driver error were caused by either recognition or decision error. Another study by Treat and colleagues (1979) concluded that human factors were the probable cause in 93% of traffic accidents. Improper lookout or an improper visual survey of the roadway accounted for 23% of accidents and inattention for 15% of human factors related collisions. Improper lookout was defined as inadequate visual search of the driving environment. Inattention was defined as a delay in detecting decelerating or stopped traffic or failure to observe critical signs and signals.

Warning signs are placed along the side of roadways to alert drivers to the alignment of roads (e.g. road curves to the right), intersections and junctions (e.g. hidden intersections or railway crossings), and provide advance warning of traffic control devices such as a traffic lights or stop signs ahead. Warning signs may also alert drivers to road obstacles such as a steep

descent or slippery roads. In locations such as school zones road warning signs alert drivers to pedestrians and/or cyclists (Castro & Horberry, 2004). Warning signs should aid in the perception of road situations and help drivers select the correct behavioral response to avoid collision and other types of traffic accidents. Singh's evaluation (2015) suggests that road warning signs are ineffective because they do not prepare and or cause drivers to attend to relevant areas of the road and subsequently select the proper action. Previous studies have questioned if traffic warning signs alter the behavior of drivers (Al-Kaisy, Hardy, & Nemfakos, 2008) and found they are ineffective in doing so (Fisher, 1992). It is possible that crashes caused by driver recognition error and decision error could in part be caused by the way signs are traditionally presented to drivers in overhead and roadside locations.

Situation Awareness (SA) can be defined as the perception of relevant elements in the environment (level 1 SA), the comprehension of what these elements or the combination of elements mean (level 2 SA) and using this information to predict the status of the environment in the near future (level 3 SA), while keeping a goal in mind (Endsley, 1995a). The topic of SA will be revisited in more detail later in the text.

Factors such as the time of day, comprehensibility, and colors used in a sign can influence how efficiently a scene is searched and a sign is found, which is necessary to ensuring a high level of SA (Zwahlen, Hu, Sunkara, & Duffus, 1991; Ben-Bassat and Shinar, 2006; Inman, Balk, & Perez, 2013). The advent of in vehicle technology has created a possibility for driver SA to be improved. Technology such as Head Up Displays (HUDs) present driving information such as navigation direction, speed limit, outside temperature and phone call ID information onto the windshield (Pretz, 2015). Recently, augmented reality (AR) cues have been integrated into

HUDs. AR uses simulated images or graphics on a transparent medium (the windshield), superimposed over real world objects or environments (Wickens et al., 2013). AR HUDs have the capability of displaying directions, notifications, and warning cues for potential hazards without having drivers take their eyes away from the road (Gabbard, Fitch, & Kim, 2014).

Providing drivers with warning signs via a HUD has been shown to increase stopping at intersections, improve speed limit detection and speed adjustment in simulated driving environments (Caird, Chisholm, & Lockhart, 2008; Liu, 2003). However there is limited research examining the effect of presenting driving critical information such as warning signs via an HUD. This thesis examines factors in the way hazard information specifically warning signs can be presented to North American drivers via HUDs to facilitate timely perception and ensure a high level of SA. I will review the relevant literature on road warning signs, situation awareness, attention, visual search, in-vehicle displays, specifically HUDs and then describe what was done to explore the affects of HUDs on driver attention and SA.

Function of Warning Signs

Warning signs are encountered on any drive (Figure 1 provides examples of various sign types). Warning signs are subcategorized based on the road conditions and situations they reference. They indicate the alignment of roads, approaching intersections and junctions, and warn drivers of upcoming traffic control devices such as a traffic lights or stop signs ahead. Castro and Horberry's (2004) book on the human factors related to signs is the main source referred to given its contribution to the field.

There is a distinction between warning and regulatory signs (Figure 1a and 1b). Although both are important to drivers, warning signs signal the nature and possible hazards on the road ahead. Regulatory signs notify drivers of restrictions and prohibitions (Castro & Horberry, 2004). An ice warning sign is an example of a warning sign whereas a speed limit sign is an example of a regulatory sign.

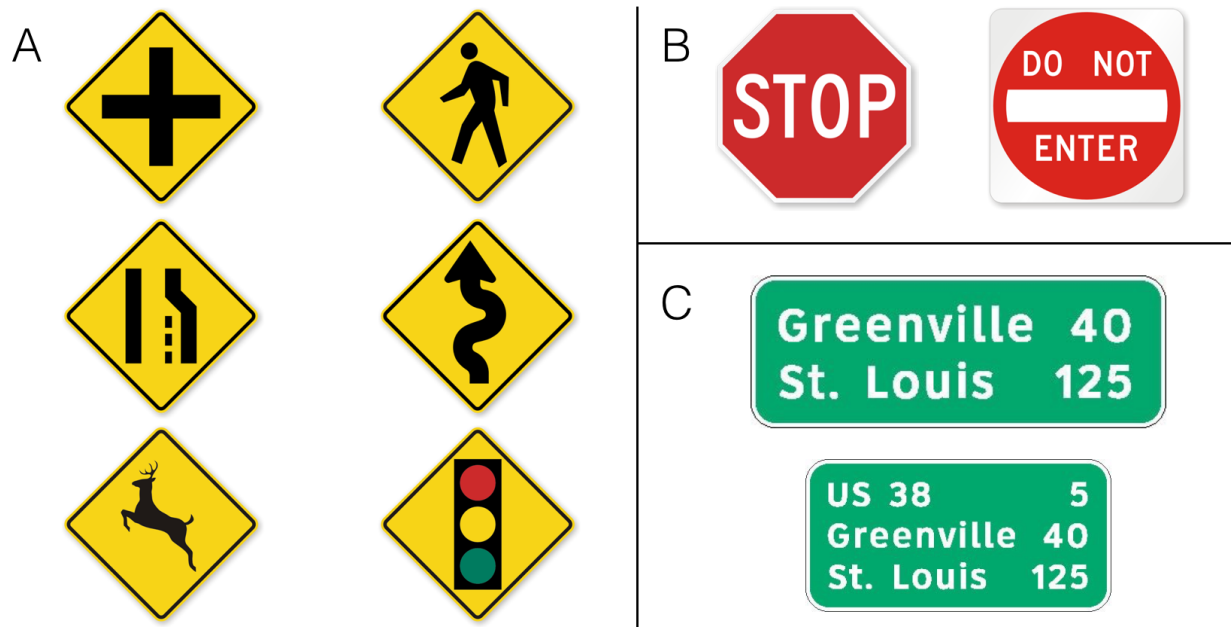


Figure 1. A- warning signs. B- Regulatory signs C- Indication Signs (USA TrafficSigns)

The function of an official road sign is to provide the user with information related to driving, making signs integral to safety on the roadway. According to the International Commission on Illumination, a sign is a device that provides a visual message based on the context it is displayed in, its shape, color, pattern, symbols and alphanumeric characters. The short message contained in the sign is designed to convey information the user will understand.

The designer of a sign must consider the perceptual and cognitive abilities of the driver as well as the environments in which the sign needs to be interpreted (Castro & Horberry, 2004).

Although a well designed warning sign may influence a driver's behavior, other factors play a role in the effectiveness of warning signs. A driver's motivation to notice warning signs, familiarity with the road or the driver's level of SA may influence the effectiveness of warning signs (Castro & Horberry, 2004). Warning signs need to be presented to drivers in the proper format, at an appropriate time, and in an appropriate location to be perceived and acted upon.

For traffic signs to be effective they should be interpretable at a glance, allowing the driver to make a timely decision with the information provided (Castro & Horberry, 2004). Traffic signs may lose their effectiveness if they are not congruent to driver expectations, easily confused with other signs, poorly maintained or illegible, obscured by environmental factors such as fog or smoke, hidden by trees, or hidden because of the way the road is laid out (Castro & Horberry, 2004). A survey of 26 State Departments of Transportations (DOT), which are responsible for the placement and maintenance of road signs, examined the effectiveness of static warning signs for occasional hazards such as ice warning signs. The survey found that 18% of DOTs viewed the signs as effective, 7% as ineffective, 4% were not sure and 71% viewed the signs as somewhat effective (Al-Kaisy, Hardy, & Nemfakos, 2008). From this survey it is clear that the organizations responsible for road sign maintenance are unsure about sign effectiveness. Similarly a Washington state investigation found that ice warning signs were not effective in decreasing the severity and frequency of ice-related accidents (Carson & Mannering, 2001). The combination of warning signs being present all of the time and the hazards they are warning for being present infrequently may cause drivers to ignore warning signs. It is possible to tailor sign

presentation to the probability of the hazard being present. For example ice warning signs may be more effective in reducing the number of ice-related accidents if visible to drivers only during winter months. Signs also can be ineffective in changing driving behavior in the rare instances when the hazards they are warning for are present. Signs may become ineffective because drivers become familiar with a route (Charlton, & Starkey, 2012), increasing the risk for accidents and unsafe behavior.

Road signs must be detectable, legible and comprehensible to be effective (Castro & Horberry, 2004). A road sign must first be visible to the driver to be detected. Thus a sign must be put in a location where it is not blocked by other objects or vehicles, and be large enough to be legible to drivers. For example, in the city where there can be many parked cars, signs need to be located higher to ensure visibility to drivers. In more rural areas, where speed limits may be high, signs must be large enough so drivers can read and react before they reach the hazard the sign is warning for (Castro & Horberry, 2004). Clutter hinders the ability of drivers to locate signs. Ho, Scialfa, Caird, & Graw (2001) had participants classify driving scenes into high and low clutter categories. These scenes were later searched for target signs which were either present or absent. In high clutter scenes participants made more sign identification errors and required more frequent and longer fixations to locate signs compared to low clutter scenes.

Time of day has been shown to influence sign recognition and recall. Shinar and Drory (1983) demonstrated that sign recognition and recall rates were better during nighttime than daytime driving, although both conditions produced worse than desired recall and recognition rates (the best performance was a recognition rate of 20% at night). One possible explanation is that drivers may ignore road signs during the day because they believe they can get the necessary

information from the road ahead. At night drivers must use road signs because headlights only illuminate a limited area of the forward roadway (Shinar & Drory, 1983).

Signs must be well lit to be seen. Adequate illumination depends on the driving condition, the color of the sign as well as the visual characteristics of the driver (Castro & Horberry, 2004). In a laboratory study on traffic signs Schnell, Aktan, and Li (2004) found that sign type, background luminance and background contrast were significant factors in determining sign recognition distance at night. Traffic signs containing high symbol to background contrasts facilitated better recognition. When sign contrast was high, background luminance above 82 cd/m² had a marginal effect of increasing recognition distance (Schnell et al., 2004). For a sign to be effective it must also be conspicuous. That is, a sign must attract the driver's attention within a short period of time even if it is located outside of the driver's direct line of sight (Inman et al., 2013). A conspicuous sign will lead to fast and efficient detection. Sign conspicuity is a function of the sign itself and the environment in which the sign is placed. Signs with yellow or fluorescent yellow backgrounds are detected more often than black and white signs in urban environments. Black and white signs placed in rural areas are detected more often than yellow or fluorescent yellow signs (Inman et al., 2013). Thus, signs and the environment they are placed in need to be considered to when examining sign detection by drivers.

Drivers must be able to read a traffic sign to be able to process information that they may later have to act upon. A field study by Zwahlen et al. (1991) determined that symbol signs had approximately twice the viewing recognition distance compared to alphanumeric signs. Viewing signs in the daytime produced viewing recognition distances 1.2 times that of the same signs at

night, and drivers were able to recognize signs placed on the right side of the road from further away than signs placed on the left side of the road (Zwahlen et al., 1991). Drivers' expectations can influence their deployment of attention, which affects the perception of traffic signs that contain important driving information.

Sign information must also be comprehensible by the driver. The driver must be able to associate the pattern viewed on the sign with some pattern stored in memory (Castro & Horberry, 2004). Ben-Bassat and Shinar (2006) evaluated comprehension level of road signs (percentage correct responses for sign meaning). It was found that the ergonomic sign design principles of compatibility, familiarity and standardization were significant predictors of sign comprehension level (Ben-Bassat & Shinar, 2006). Compatibility refers to physical and conceptual properties that a sign represents. A sign is said to be compatible if what it depicts matches the physical and conceptual properties of the road. For example, a sign that warns the road is turning to the right in a area where the road turns to the right is said to be compatible. Familiarity refers to the frequency with which a driver encounters a specific sign. A pedestrian warning sign is frequent and is therefore more comprehensible than a sign that is not encountered by drivers often. Last, standardization refers to the consistency of colors and symbols used in signs that present the same message. Signs that represent the same message with the same form are said to be standardized (Ben-Bassat & Shinar, 2006). For example a sign that warns for a steep descent should be standard across all situations where signs are placed to warn drivers of a steep hill.

The last indicator of an effective sign is the driver's response to the sign. A response has two components; a cognitive response and a physical response. A cognitive response is triggered by the fact that the driver has perceived the sign as being important. Sign importance is

determined by previous driving experience and by drivers considering whether or not signs have been helpful in affecting their well being (Castro & Horberry, 2004). When a sign is deemed important a driver must recognize that the sign requires some kind of response and initiate it immediately or in the near future. Fisher (1992) examined the relationship between a driver's ability to recall traffic signs and to appropriately modify their driving behavior. In one condition where hazards were visible from the position of the traffic sign, 56% of drivers were able to recall the sign. Of the drivers who were able to accurately recall the sign only 46% correctly modified their driving behavior. On the other hand the of 44% of drivers who failed to correctly recall the sign, 39% correctly modified their driving behavior. In the second experimental condition the traffic hazards were not visible from the location of the sign. In this case 56% of participants were able to correctly recall signs, but only 28% appropriately modified their behavior (Fisher, 1992). It is clear that the connection between being able to remember what a traffic sign depicts and adjusting driving behavior is not simple. The co-presence of a warning sign and the hazard may interact to increase the chances of the correct response when compared to situations where drivers are presented with a warning sign when the hazard is not visible. What is not understood is what steps occur between perception and action. The low rates of sign recall suggest that being able to recall signs that have been passed is not always necessary for correct action. However it is plausible that being able to recall signs does improve the chances of appropriately responding to driving conditions. It would be of value to know what elements of the driving environment are attended. Knowing if there are ways to direct the attention of drivers to important elements would be a big step in allowing drivers to select the correct behavior for the situation they find themselves in.

Situation Awareness

Driving safely requires a minimal level of SA. To achieve level 1 SA a driver must first perceive relevant elements in the driving environment. From this initial perception a driver must be able to understand what the relevant pieces of information are and how they interact with one another to gain level 2 SA. The driver then must be able to accurately predict future road conditions, which is level 3 SA. Accurate prediction of future road events should allow the driver to select behavior to appropriately and safely navigate their vehicle.

When evaluating situations and environments within the SA model it should be noted that the levels of SA do not need to be completed in a linear, stepwise fashion. People will not always progress from level 1, to level 2, to level 3 SA. Logic suggests that the perception of task relevant information (level 1 SA) is needed to be able to predict the future state of the environment (level 3 SA). Based on their existing knowledge of the specific driving domain and its current condition, a driver may direct attention to specific locations in the environment (level 1 SA). For example a driver in an unfamiliar urban area may direct attention to the sides of the road for pedestrians who may unexpectedly try to cross the street. Drivers more familiar with an urban area are less likely to constantly scan the roadside for pedestrians who may cross the street because they have learned where pedestrians are most likely to be, and are able to deploy attention more efficiently. When a driver begins to develop a better understanding of how environmental elements interact and influence one another (Level 2 SA) they may return to level 1 and direct their attention in a more precise manner to more informative areas of the environment than they would have with a limited understanding of their environment, further increasing their level 2 SA. Thus, a driver is more likely to alter scanning behavior to more closely monitor the

roadside near restaurants or other popular attractions where pedestrians are more likely to cross the road.

People revert back to a lower level of SA when they acquire more information and a deeper understanding of their current environment. With experience in a specific context drivers can learn how various environmental elements interact (time of day, road and weather conditions, and types of business in area) to more effectively survey their surroundings. This process of refining a visual search to survey more informative parts of the environment may lead to an increased level 2 SA. This iterative accumulation of understating how to survey for and integrate domain specific information eventually allows a person to be able to achieve level 3 SA where they are able to accurately predict the future state of the environment (Endsley, 1995a).

The results of Fisher's (1992) study on sign recognition, recall and drivers responses can be understood in the SA framework. Drivers who have two pieces of relevant information in sight, the sign and its hazard (level 1 SA) are able to understand how these elements interact (level 2 SA). By achieving this understanding based on two pieces of information drivers are better able to correctly predict upcoming road conditions (level 3 SA) and adjust their behavior when compared to drivers presented with less level 1 SA information (sign only or hazard only).

Situation Awareness can be assessed using a global measure called the Situation Awareness Global Assessment Technique (SAGAT). The SAGAT assesses level 1 (perception), level 2 (comprehension) and level 3 (projection) SA by asking the operator questions related to the relevant features of the system and external environment necessary for task completion (Endsley, 1995b). In this study the SAGAT was administered at the end of the simulation and

addressed many aspects of the situation and environment. Participants were unaware they would be questioned at the end of the simulation, which allowed for them to attend to the environment as they naturally would in normal driving situations (Endsley, 1995b).

A driver's perception (level 1 SA) of relevant elements in the environment is influenced by the displays they are provided with (the dashboard etc.) or directly by their senses (Endsley, 1995a). An obvious question is whether displays can be designed to increase situation awareness and produce safer driving behavior? To answer this question it is necessary to start by examining some of the basic skills needed for driving.

Steering is one of the essential tasks in driving. The Two-Level model of steering proposed by Donges (1978) divides steering into guidance followed by control. When driving in a straight line steering requires the driver to perceive environmental information to determine a driving path (guidance). Once a driver has selected a path and is in motion they must then monitor their vehicle's location in relation to the desired path. To drive in a straight line a driver must select a path for their vehicle and maintain heading along the desired path (control). If the vehicle has deviated from the desired path the driver must correct steering to return to the desired path.

Land and Horwood (1998) restricted the vision of drivers to determine what visual information is necessary to control a vehicle. They found that drivers use information 4° degrees below the horizon to guide steering and information 7.5° below the horizon to maintain position within a lane. The combination of this information allows drivers to accurately use visual information for vehicle control, especially at high speeds (Land & Horwood, 1998). This study

demonstrates that certain areas of a driver's visual field (and the driving environment) are more valuable for completion of certain driving tasks than other areas of the visual field.

To steer effectively around curves, drivers direct their gaze to an area on the road called the tangent point. The tangent point is the location on the inside of the curve where the edge of the road reverses directions or protrudes the most. Approximately two seconds before reaching a curve in the road a driver will direct their gaze towards the tangent point and do so again three seconds into the curve. The driver's gaze angle towards the tangent point is matched by their steering angle approximately two seconds later (Land & Lee, 1994) (See Figure 2). Drivers use different patterns and time sequences when visually surveying the road to steer but consistently use the tangent point as a cue to direct steering (Land & Lee, 1994).

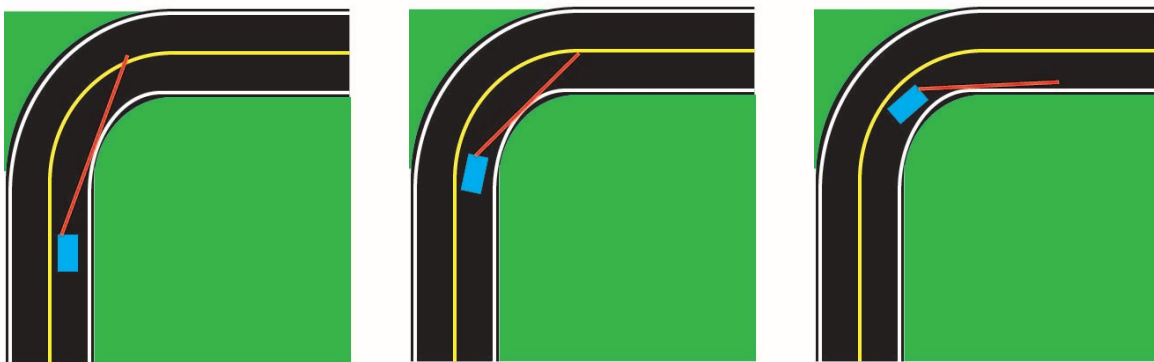


Figure 2. The tangent point is used to guide steering through corners. The red line depicts the gaze angle of the driver at various points throughout a curve. The driver's gaze angle is later matched by their steering angle.

Gap Monitoring is another key aspect of driving that involves being able to determine the distance between one's own vehicle and other vehicles on the road. Drivers must be able to maintain the gap between their vehicle and the vehicle they are following (lead vehicle) to avoid collision. Three-dimensional parameters such as the speed of and distance to the lead vehicle are

valid cues to help maintain safe gaps, however people have a hard time making accurate estimations of these parameters (Gibson & Bergman, 1954; Scialfa Guzy, Leibowitz, Garvey & Tyrrell, 1991). Anderson and Sauer (2007) found that drivers use information about changes to their retinal images, or Drive by Visual Angle (DVA) which allows drivers to determine the relative distance between their vehicle and a lead vehicle to maintain safe following distances. The DVA model proposes that drivers monitor the size (visual angle) of their retinal images to plan vehicle acceleration or deceleration. If the retinal image of the car ahead is expanding at a fast rate, this is an easily interpreted cue that the gap between vehicles is shrinking and that brakes must be applied. On the other hand, if the retinal image is shrinking it is safe to accelerate to maintain the gap to the lead vehicle.

In addition to managing gaps on straight roads it is imperative that drivers be able to accurately judge gaps in traffic when turning. Analyses of traffic data (Harwood, Mason, & Brydia, 2000) show that drivers require a 6-8 second gap when turning left or right from a minor road (one lane) onto a major road (two lane). Drivers are able to evaluate the speed of oncoming vehicles when making their judgments as to whether they can safely enter a major road and accelerate up to proper speed.

It can be seen from this short review of necessary actions to safely navigate a car that a driver must perceive a variety of cues accurately to be able to react to and predict road layout and conditions. Failure to direct attention towards relevant areas in the environment will have undesirable consequences. Warning signs are intended to increase safety by alerting the driver to the road conditions ahead. Warning signs should be designed and presented to facilitate the proper deployment of attention to ensure the high level of SA necessary for safe driving.

Attention

Attention is a large set of processes which allow us to select and process the large amount of information our sense organs receive (Wolfe et al., 2012). Attention can be divided into two categories; external attention and internal attention. External attention refers to the selection and modulation of sensory information as it enters the sensory organs. Internal attention refers to how we select and manipulate internal information, such as the contents of working memory, long term memory and response selection (Chun, Golomb & Turk-Browne, 2011). External attention can be voluntarily directed to targets and it can be attracted to salient objects or features in the environment as described below. For example a road sign that differs from the rest of the environment on one or more dimensions may attract the attention of a driver more easily than a sign that lacks salience or is similar to its environment. At any given point in time there is much more information than we can process with our limited attentional resources (Chun et al., 2011) and when driving, multiple stimuli compete for limited attentional resources. The goal of attention is to direct mental resources to pertinent objects or targets in the environment (Chun et al., 2011). Attention should be allocated to the road ahead for other vehicles and warning signs that may contain important information about future road conditions and possible hazards, and not diverted to in car audio controls or other potential distractors.

To monitor and locate relevant items in complex visual environments, we must divide our attention among several Areas of Interest (AOI's). An AOI is defined as a specific area where task related information can be found (Wickens et al., 2013). Intersections, warning signs and the speedometer are examples of AOI's that require attention when driving. It is thought that attention can be directed to environmental stimuli in various ways. External attention can be

directed endogenously or exogenously and this deployment of attention can be automatic or controlled.

Exogenous selection occurs as a result of the stimuli that we are presented with rather than our goals and plans (Theeuwes, 1994; Jonides & Yantis, 1988). For example an item with an abrupt onset automatically attracts attention. In unfamiliar environments attention is largely guided by exogenous processes. Exogenous attention should not be confused with bottom-up processing which is influenced by practice (Trick, Enns, Mills & Vavrik, 2004). When a person repeatedly carries out an action with intention it eventually becomes automatic. When an experienced driver approaches a stop sign they usually stop. The stop sign draws attention because of repeated exposure and practice. Due to repeated exposure to stop signs, the features (color, shape, size) operate in a bottom up fashion to attract the drivers attention. Humans are not born more attentive to large, octagonal, red signs with the word "Stop" in the middle, rather we learn that the combination of these features are important and should attract our attention.

Endogenous selection occurs when people have knowledge of the environment and specific goals in the environment. Expectations and goals influence how a person deploys attention and actively searches an environment. Depending on the situation or context people activate certain schemas. Schemas provide a coherent framework to help people understand information related to complex system components, states and functions (Endsley, 1995a). When information is coded into schemas some details of the situation are lost but information is more coherent and easily organized for storage, retrieval and further processing (Endsley, 1995a). Schemas influence what aspects of the environment are selected for further processing and allow people to flexibly interact with and adjust to a broad range of situations within a

certain category. A person's schema for road signs may lead them to direct attention the the right side of the road for signs when driving in North America and other regions where driving on the right side of the road is the norm. Schemas are flexible in the way that if drivers were to transition from driving on the right side to the left hand sign of the road (e.g. United States to Japan), they should be able to alter their behavior and start to search for relevant signs on the left side of the road. Endogenous selection allows signs to be located and acted on more quickly and effectively than if exogenous selection alone were to guide searches (Trick et al., 2004). While endogenous selection can help driving performance it may also harm performance when relevant information is placed in unexpected locations or presented at unexpected times. When relevant but unexpected information does not pertain to immediate goals it may be missed altogether (Trick et al., 2004).

Attention can also be categorized as automatic or controlled. Selection without awareness is automatic. Automatic selection is rapid, effortless, unconscious, and is difficult to stop or modify once it is initiated. This type of attention is initiated by certain environmental stimuli such as the sudden onset of flashing lights or a loud sound. Selection with awareness or controlled processing is effortful and slow. Unlike automatic selection, controlled processing can be started, stopped or modified however it is difficult to carry out multiple controlled processes at once (Castro, 2008). These types of attentional deployment combine to create four specific types of attention that will be outlined below. See Table 1 for an outline.

Table 1

Types of Attention Control in Driving

	Exogenous	Endogenous
Automatic	Reflex	Habit
Controlled	Exploration	Deliberation

Reflexive selection is exogenous and automatic, triggered by the presence of environmental stimuli. This type of selection is considered to be effortless and unconscious. It cannot be stopped and may occur when inappropriate. New stimuli presented within the visual field may evoke reflexive selection, however cueing people towards the location of a target prevents saccades towards irrelevant distractors (Theeuwes, Kramer, Hahn, & Irwin, 1998). During both low and high driving workload, brake lights that have a luminance flicker of 20Hz are more effective at capturing attention and help drivers stop more quickly than brake lights which are constantly illuminated (Berg, Berglund, Strang, & Baum, 2007). This is evidence that certain stimuli can evoke reflexive selection and lead to faster responses when driving.

Habitual selection is endogenous and automatic, carried out to achieve a goal in a certain context. North American drivers who are unsure of the distance to a highway exit may habitually deploy attention to the right side of the road in search of an exit indication sign. In this specific context, deployment of attention to the side of the road is automatic. Experienced drivers viewed a video and were asked to look for hazards (Langham, Hole, Edwards, & O'neil, 2002). In the video a police car with normal markings and flashing lights was parked in an unusual position (at a 45° angle) or a normal position (in line with road) along the right side of a

highway. The police cars parked in line with the road were less likely to be noticed by the participants despite the presence of police markings and flashing lights which should have been conspicuous enough to be detected. Langham and colleagues' (2002) rationale was that experience tells drivers that flashing lights of a vehicle parallel to theirs is a moving police car, so a driver may divert their attention away from this object after initially noticing it. Habit leads a driver to deploy their attention elsewhere, ignoring other cues that the car is not moving, increasing the risk of a collision. A car parked at a 45° angle does not fit into the class of a usual stimuli, therefore habitual attention deployment is disrupted. In the case of a novel stimulus, drivers adjust behavior accordingly. Changing environmental stimuli may change habitual attention deployment schedules and allow for the accurate and timely perception of hazards (Langham et al., 2002).

Selection by exploration is exogenous and controlled. It occurs when a driver is exploring an unfamiliar environment, with the goal of information gathering. If a driver believes that the driving demands are low, they may choose to explore their environment (Trick et al., 2004). A driver chooses to process certain stimuli and is able to shift his or her attention to another location when necessary. Salient stimuli attract attention through exploration, which may explain why drivers are more likely to recognize and recall signs at nighttime compared to daytime (Shinar & Drory, 1983). At night the reflective traffic signs may be more salient than other environmental features which are not well lit, thereby attracting attention.

Selection by deliberation is controlled and endogenous deployment of attention. This type of attention is directed by goals or plans. A driver may direct attention to the location of street signs if they are attempting to search for a street in an unfamiliar neighborhood. This type

of selection allows us to integrate new information into current goals, affording the ability to change behavior rapidly. The problem with selection through deliberation is that it needs to be done consciously and is therefore subject to interference by other tasks (Trick et al., 2004). For example when searching for a specific highway exit a driver can deploy attention to the right side of the highway or overhead in search of large green signs which will alert them to their exit. Prior knowledge of highways and where exit signs are located allows drivers to direct attention appropriately. If however the driver needs to react to a surprise event such as a deer crossing the highway, the search task may be disrupted and the sign they are seeking may be missed altogether.

The driving specific attentional framework mentioned above will be applied to this research. Laboratory studies on attention usually have participants search for a distinct target in a field of distractors. Targets can be defined by color, orientation, or a combination of these distinguishing characteristics. These studies have found that an abrupt distractor added to the display increases search times. Participants were unable to ignore abrupt onset stimuli regardless of the color of the distracting element and regardless of the color target description they were given (Jonides & Yantis, 1988; Theeuwes, 1994). These results indicate that elements with an abrupt onset have a negative effect on attention.

Results from simple attention and visual search experiments may be internally valid. Although valid, these results need to be carefully interpreted when applied to a more complex search environments such as those encountered by drivers. The driving environment contains many targets and distractors that are constantly changing, making it fundamentally different from the search displays encountered by participants in most laboratory studies. It is possible that

when engaged in driving tasks abrupt onset stimuli may not negatively affect overall driving performance. If implemented correctly, an abrupt onset stimuli presented via a HUD may lead drivers to attend to the correct locations in the driving environment and achieve a high level of SA, resulting in safe driving and fewer accidents.

Eye-Tracking

The high visual demands required by driving present the opportunity for the use of eye-tracking to determine where a person is attending at a specific point in time. There are three basic types of eye behavior that are of interest to this research. The first is fixation and the other two are eye movements called saccades and smooth pursuit. Fixations are defined as the point in time when the eye is still and the fovea, the area of the retina with the highest visual acuity, is focused on an object and information is being taken in (Land, 2006). A driver may fixate on a sign to gather information about what hazards are ahead. Saccades are fast movements of the eye that bring selected targets or new parts of the environment into view (Kowler, 2011; Land, 2006). Drivers will make many saccades between relevant driving information sources such as the location of other vehicles, hazard signs and pedestrians. Smooth pursuit refers to smooth tracking of a target. Targets moving thorough a person's visual field at up to 75 deg/s can be tracked using smooth pursuit (Buizza & Schmid, 1986) Most visual scenes contain various moving elements. Because of the large number of visual stimuli present at any point attention is involved in selecting what target we decided to fixate and smooth pursue across a scene (Kowler, 2011). For example when drivers recognize they are driving through an area with many pedestrians they may shift their attention to the task of looking for pedestrians. This many be manifested in more

saccades to pedestrians and smooth pursuit eye movements to pedestrians moving through the environment.

Eye-tracking has been used as a method to determine whether experience plays a role in drivers' ability to recognize hazards (Pradhan, Hammel, Deramus, Pollatsek, Noyce, & Fisher, 2005). Eye-tracking can provide a clue as to where external attention is being directed. For example if someone is looking directly at a traffic light it is likely they are attending to the traffic light. What eye-tracking can not tell us is what objects have been registered in the participants periphery and whether what has been looked at has been processed (Endsley, 1995b). In the context of SA eye-tracking can tell us what individual elements of the environment are looked at (level 1 SA) but cannot tell us what elements of the situation are being mentally manipulated (level 2 SA) and how these elements allow a person to predict the future state of the environment (level 3 SA). For example a participant does not need to look directly at the edge of the road to be able to tell that it is curving to the left or right to accurately predict that the road will soon require them to steer (Land & Lee, 1994). This information about which way the road is turning is combined with other pieces of information to achieve a certain level of SA. Eye-tracking can provide some clues as to where a driver is attending but it is not guaranteed that looking equates to seeing and understanding which are necessary for a high level of SA.

Visual Search and Driving

A visual search requires that a target object be found in a field that contains distractors (Wickens, Hollands, Banbury, & Parasuraman, 2013). For simple visual searches the target is predefined and embedded within a field of distractors. However in real-world situations there

may be multiple possible targets in the presence of changing and moving distractors (Wickens et al., 2013). In situations where people have experience with a task or the search environment and need to search various displays or various locations for targets, visual attention is directed to AOIs. One AOI may provide information about multiple tasks. For example, looking through the windshield of a car can serve the tasks of lane keeping and hazard monitoring (Wickens et al., 2013). The SEEV Model states that the salience, effort, expectancy and value of targets predict where a person is attending at any given time (Wickens et al., 2013).

Salience refers to the extent to which a target stands out from other items. Through a series of experiments where participants searched for target characters among distractors, Duncan and Humphreys (1989) showed that when similarity between search target and non-target is high a search is inefficient and difficult. On the other hand when target and non-target similarity is low, a search is efficient. In a situation where a target is dissimilar to non-targets, all non-targets can be given the same low priority weight and eliminated, making a search easy. For example when driving along an unfamiliar road at night one may be searching for signs to help guide driving. One may be unaware of what potential target signs may be, but the criteria for the targets are that they will have high reflectance and be near the right edge of the road. This allows drivers to disregard items that don't fit the target description. Items given low priority will include shrubbery along the side of the roadway which can be considered green distractors despite the slight variation in shade and location of the shrubs. The large difference in the description between the target (the sign) and all of the distractors (shrubs etc.) will lead to an efficient search for relevant road signs.

Effort refers to the cost of shifting attention from one AOI to another. It takes more effort to move the eyes large distances than to move the eyes small distances to gather information. For example when driving, if two pieces of information are located directly in the center of a person's field of view, little effort is needed to shift attention between the two AOI's. On the other hand, if drivers need to shift their eyes from the center of their field of view to the right side of the road, where signs are usually located, more effort is required. Finally a large amount of effort is needed for a driver to check the blindspot before changing lanes. Checking the blindspot requires movement of the eyes, head and torso are required. Rather than devoting large amounts of effort to attend to stimuli a person may rely on memory to make their decisions (Wickens, 2014), which may lead to dangerous lane changes.

People usually look at places where they *expect* information or targets to appear. Borowsky, Shiner and Parmet (2008) showed experienced drivers pictures of road scenes where signs appeared in a variety of expected and unexpected locations. They demonstrated that drivers may fail to detect road signs when placed in unexpected locations. Participants were more likely to identify no right turn traffic signs when they were placed on the right side of the road compared to when placed on the left side of the road. Schemas provide an information processing structure to explain how people seek to process information depending on the situation or context in which it is provided. Schemas allow people to integrate new information from their environment with old schema-based information, influencing perception and comprehension (Brewer & Treyens, 1981). Drivers activate specific schemas when driving to help them more quickly identify relevant information and quickly select a response. As described earlier, in countries where driving on the right side of the road is custom, drivers'

schema leads them to look to the right side of the road when searching for signs. Similarly when a person is driving through a school zone their schema for school zones should lead to them reduce their speed and more diligently survey the area for children who may cross the road at unpredictable times. Knowing which schema to select for specific driving situations should better allow drivers to survey the correct AOI's and improve safety.

AOI's that present valuable information are attended to more often than areas that do not contain valuable information (Wickens et al., 2013). *Value* can be thought of as the importance of elements in a persons field of view. Value is the combination of the priority given to certain AOI's and their relevance to a specific task (Horrey, Wickens & Consalus, 2006). For example, a billboard usually has low value to a driver because it is not directly relevant to the task of driving. A driver will not give billboards high priority in their road scanning behavior. Warning signs on the other hand will be of high value to drivers. Attending to warning signs will alert drivers to upcoming road conditions and aid in the selection of the appropriate response.

Failure to complete a successful visual search may be attributed to a lack of attention being deployed to relevant AOI's. Change blindness occurs when changes to objects, photographs, motion pictures or natural scenes are not noticed from one moment to the next (Martens, 2011; O'Regan, Rensink, & Clark, 1999). O'Regan et al. (1999) presented participants with static images where high contrast shapes were briefly spattered over a picture, similar to mud or other debris hitting a windshield. Although these disruptions did not mask the locations of changes made to the images, participants failed to notice the changes. In a second experiment, black and white textured rectangles were used as visual masks instead of 'mudsplashes' to cover the area of the photograph that was subsequently changed. It was found that change detection

was much higher in the second experiment, providing evidence that changes are noticed when made in locations of central interest (O'Regan et al., 1999). It appears that the mask attracted a person's attention when placed over the area of the image that was later changed. When the mask was removed attention was still focused on the location, allowing changes to be noticed.

Simons and Chabris (1999) showed participants a video and asked them to count the number of times a ball was passed between members of a team. During the video an unexpected event occurred where either a person in a gorilla suit or a woman with an umbrella walked through the scene. Across all experimental conditions 54% of participants noticed the unexpected event and 46% failed to notice the unexpected event, demonstrating that being engaged in a task can cause people to experience inattention blindness and miss salient stimuli directly in view (Simons & Chabris, 1999). This finding is relevant to driving because it implies that if drivers are engaged in a specific type of road monitoring task they may miss unexpected events.

Martens (1999) demonstrated that when watching videos of driving scenes participants failed to notice relevant changes to signs along the route. Even when participants looked at locations where changes occurred they often missed the changes (Martens, 1999). It should be noted that large changes to the content of signs as well as an auditory signal indicating that a change was about to happen reduced the incidence of change blindness. Thus even if changes to the driving environment are significant, it is no guarantee that people will be able to perceive them and take appropriate action. Martens showed that providing observers with auditory cues can alert them to impending changes and possibly alter their search patterns and/or criteria, which may lead to a reduction in change blindness.

Charlton (2006) asked participants to watch driving videos and report what they noticed. Initially Charlton asked participants to say out loud what items attracted their attention. In the second part of this experiment Charlton asked participants to report when they noticed a hazard or hazard warning sign. Participants did not notice a significantly different number of items depending on instructions. However when explicitly asked to look for hazards and hazard signs, participants noticed more than when simply asked to name objects that attract their attention. These results suggest that warning signs in their current form do not have a high degree of attentional conspicuity. In regular driving conditions drivers may not attend to warning signs, possibly preventing them from acquiring necessary information to drive safely.

In driving situations when drivers do not have a specific goal and are under reflexive attentional control it is of interest to know what areas of the environment have a high degree of attentional conspicuity, or attract a drivers attention. It is of interest to know what can be done to direct the attention of drivers to informative locations in the environment such as warning signs, allowing drivers to select appropriate and safe behavior for their given situation. Previous research has yet to explore and identify the relationship between attention to hazard signs and a driver's SA.

In-Vehicle Displays

It may be difficult to shift attention to important AOI's depending on the road situation as well as the driver's mental state. Displays are a means of supporting tasks that require divided attention without compromising attention required for the primary task (Wickens et al., 2013). If a display can alert a driver to possible changes in the road or driving environment and shift the

focus of attention to relevant areas, the driver may have increased SA and be better prepared to safely navigate their vehicle. Displays may help drivers notice subtle but important changes to roadways they frequently travel, thus helping reduce the number of traffic accidents related to change or inattention blindness (Wickens et al., 2013). As reviewed earlier many accidents are a result of a failure in perception and inappropriate reaction to relevant environmental stimuli.

A display warning sign system may be designed to alert an inattentive or distracted driver to an upcoming hidden intersection. Even if the driver is not distracted it is possible that the warning sign for this intersection may be ill-placed or occluded by other vehicles or objects. Since the warning system may alert the driver to the hidden intersection they may be able to shift their attention to the task of monitoring the roadway for cars crossing the upcoming hidden intersection.

Head Up Displays (HUDs)

To effectively drive, a person must be able to maintain awareness of the road, other vehicles and pedestrians (far domain) as well as in vehicle instruments (near domain). HUDs were first used in airplanes in 1960 (Liu, 2003) and adopted for automobiles in the late 1980s (Pretz, 2015). Traditional automobile HUDs superimpose information relevant to the driver such as navigation direction, speed limit, outside temperature and phone call ID information onto the windshield (Pretz, 2015). Information provided in a HUD can help a driver with navigating their vehicle (speed information, navigation information) as well as cell phone information. HUDs are designed to help reduce the effort or cost associated with attending to two different areas of

interest by placing information from the two different areas close to each other (Wickens et al., 2013).

Currently there exists an opportunity for AR cues to be integrated into traditional HUDs. AR uses simulated images or graphics on a transparent medium (the windshield), superimposed over real world objects or environments (Wickens et al., 2013). AR HUDs have the capability of displaying lane keeping information (Kork, 2016), traffic information, navigation information with suggested speed, traffic signs, street signs (Rao, Tropper, Grunler, Hammori, & Chakraborty, 2014), vehicle status notifications, and warning cues for potential hazards without having drivers take their eyes away from the road (Gabbard, Fitch, & Kim, 2014).

Items displayed in the AR HUD can either be screen-fixed or world-fixed. Screen-fixed graphics are not attached to specific locations in the real world, whereas world-fixed or conformal graphics will stay attached to the objects in the world (Gabbard, et al., 2014). For example a screen-fixed AR HUD may display a hazard warning sign for a deer crossing in the bottom portion of the windshield and this icon will remain in view until the hazard is no longer present. A world-fixed AR HUD icon for a deer warning sign will change location as the sign approaches. That is, the sign will get larger and its location on the screen will change as the car approaches the sign, conforming to the driver's perception and the physical reality of the sign. According to Gabbard, et al. (2014) world-fixed HUD's may be better suited for displaying primary driving related information such as navigation information and warning alerts (warning signs) whereas screen fixed HUD's may be better for displaying information unrelated to the outside world but still relevant to driving such as speed and fuel level (Gabbard, et al., 2014).

Presenting drivers with information in a HUD is thought to improve safe driving behavior. A driving simulator was used to test the effect of providing participants with intersection warning signs in a HUD. It was found that signs presented in a HUD led to more drivers stopping at intersections (Caird et al., 2008). HUDs have also been shown to improve driver response time in detecting and adjusting speed in response to speed limit changes and road-side signs in both high- and low-load driving conditions (Liu, 2003).

Potential drawbacks of HUDs must also be considered. Turfano (1997) outlined possible negative effects on perception and attention that HUDs may produce. There seems to be some disagreement on what depth to focus the HUD image in screen fixed HUDs. It was decided that the best distance was between 2m and 2.5m away from the driver. At this distance HUD images appear to be at or just beyond the front of the vehicle. The problem with focusing the image at this distance is that when a driver fixates on the HUD image, objects in the distance will be distorted. Objects in the distance appear to be smaller and the driver therefore assumes they are further away than they truly are. This perceptual illusion could lead to an increase in accidents for drivers using HUDs. Another concern with HUDs has to do with their negative effect on a driver's attention. It is possible that a HUD may capture too much attention, a phenomenon known as cognitive capture (Turfano, 1997). A driver may focus on the elements of the HUD rather than the elements in the real world. It is clear that if the HUD is intended to help the driver, it should not attract so much of the driver's attention that the outside world is ignored. There is ongoing research to determine the specific elements that should be presented to drivers in a HUD as well as the type of driving situations in which this information should be presented to possibly increase drivers' SA.

Rationale

As seen above many factors contribute to the effectiveness of road warning signs. It can be assumed that failure to quickly and accurately perceive and react to warning signs can reduce their effectiveness and result in a decrease in driver SA, leading to unsafe driving behavior. It may be beneficial to present drivers with signs or the information contained in signs in an easily recognizable form and at a predictable location, such as on a HUD. Presenting drivers with sign information in a HUD may increase the effectiveness of pre-existing signs. HUDs may allow for drivers to predict the future environmental state (level 3 SA) allowing for a high level of SA. A HUD may ensure that warning signs critical to safe driving are visible to drivers, facilitating the achievement of level 1 SA, which is necessary for the achievement of level 2 and 3 SA.

Drivers must divide their limited attentional resources among various sub-tasks to successfully drive. Tasks such as steering, gap monitoring, speed maintenance, pedestrian avoidance and the search for traffic signs must be done concurrently or in rapid succession. These tasks can be made more difficult in complex environments such as in city driving, causing relevant stimuli to be missed. Displays can direct drivers attention to relevant AOIs by increasing their salience and their value, reducing the effort to attend to them and by presenting relevant information information in predictable locations. Directing drivers' attention to the correct locations will allow for quick perception and integration of available road information, eventually leading to a high level of situation awareness. Warning signs presented in HUDs may also reduce the effort required by drivers to search for signs in the road environment as they will be easily perceptible in a standard location, the windshield. Drivers will not have to worry about the value of signs being presented via the HUD because only information deemed

important will be displayed. Ensuring the accurate and timely perception of warning signs are is the first step towards reaching a level of SA necessary for safe driving.

Research Questions

The main question that this research seeks to investigate is how presenting warning signs via AR HUDs can affect the way in which drivers deploy their attention and acquire SA.

A secondary research question seeks to determine if the driving environment (city vs rural) and display type have any impact on the way in which drivers deploy their attention and its effect on their subsequent level of SA.

Measures

To assess the attentional conspicuity of warning signs as well as other items in the driving environment, participants were instructed to attend to the road environment as they would if they were driving the vehicle that the video was shot from and to verbalize what items attracted their attention (Charlton, 2006). This method allowed us to compare how various items in the driving environment captured attention when interacting with an AR HUD versus no AR HUD.

As mentioned above The SAGAT assesses level 1 (perception), level 2 (comprehension) and level 3 (projection) SA by asking the driver questions related to the relevant features of the car and external environment necessary for safe driving (Endsley, 1995b). By asking participants questions related to all aspects of the driving environment the SAGAT allows for overall SA to be measured. The SAGAT was used to determine the effect of interacting with a AR HUD drivers' SA.

A "surprise event" in the form of a pedestrian walking across the road at a mid-block location took place during the final video clip participants viewed. This type of behavior is typical of pedestrians who are involved in collisions with vehicles (Chrysler, Ahmad, & Schwarz, 2015). This surprise event helped determine if participants interacting with a AR HUD are at a higher risk of missing critical events similar to these these. To determine if participants noticed the surprise event they were asked if they noticed anything unusual during the video in reference to the surprise event.

Eye-tracking was used as a behavioral measure of drivers' attention. The duration and number of fixations to warning signs, other vehicles and the surprise event were measures of interest in this study. If drivers with AR HUDs made one long fixation towards a warning sign rather than multiple fixations as drivers without AR HUDs may do, than this could be possible evidence of cognitive capture, a drawback of HUDs (Turfano, 1997). Eye-tracking was also used to determine is drivers experienced inattention blindness. Drivers who looked at the pedestrian crossing the street during the surprise event and did not report noticing the pedestrian were considered to have experienced inattention blindness. If significantly more participants in the AR HUD group miss the pedestrian cross the street the street than it is possible that AR HUDs have a negative effect on drivers attention and eye movement behavior.

Method

Participants

There were 38 students (25 men and 13 women) from the Rochester Institute of Technology tested in this study. Participants were provided with class credit for participation or

volunteered for no reward. Participants needed a valid drivers license, normal or corrected to normal vision, and normal color vision to participate in this study. The average age of participants was 20.7 years old (S.D. = 3.2) and ranged from 18 to 30 years old. On average participants had a full drivers licence for 3.8 years (S.D. = 3.1) and had an average of 0.4 (S.D. = 0.7) traffic accidents in the past five years. 28 of the 38 participants were asked if they knew where the experimental videos were filmed. Of these 28 participants 7 were able to accurately identify where videos were filmed.

Apparatus & Stimuli

The experimental stimuli were presented to participants on a mid 2010 27 inch iMac with a 2.93 GHz Intel Core i7 processor and a ATI Radeon HD 5750 1024 graphics card. Participants viewed video clips of both high clutter and low clutter driving routes (within subjects factor). Participants either viewed video clips with no HUD or a world fixed HUD (between subjects factor). Video clips were recorded with a GoPro4 hd camera mounted to the windshield of a 2015 Ford Focus. The video was shot from a perspective that mimicked the outward view from the driver's seat. All videos were shot in Irondequoit, New York. High clutter videos were shot on St. Paul Boulevard. St. Paul Blvd. is mainly two lanes in each direction with a center turning lane on some parts of the road. A short portion of the road in the high clutter video has one lane of traffic in each direction with a center turning lane. St. Paul Boulevard can be classified as a residential area. The high clutter video had houses and sidewalks on both sides of the roads (Figure 3).



Figure 3. A screenshot of the high clutter driving environment participants viewed during the study.



Figure 4. A screenshot of the low clutter driving environment participants viewed during the study.

Low clutter video was shot on King's Highway and Lake Shore Boulevard. The majority of the road in the low clutter video is one lane in each direction. A small portion of the low clutter video, a section of road on Lake Shore Boulevard has one lane in each direction and a center turning lane. The low clutter video was mostly shot in parkland, there were fewer than ten residential buildings in the entire low clutter video (Figure 4).

The video footage was edited with Adobe AfterEffects to contain hazard warning signs in a world fixed HUD format. Warning signs were made visible to participants for 3 seconds before they were out of view (passed). Warning signs in the world-fixed HUD were 100% opaque (0% of light was able to pass through sign). A "surprise event" in the form of a pedestrian walking across the road at a mid-block location was included in one of each type of video. In low clutter videos the surprise event pedestrian was visible from 4:57 to 5:02 and from 4:13 to 4:17 in the high clutter video. Videos were between 4:45 to 5:36 minutes in duration.

A third generation Positive Science model METL eye-tracker was used to capture visual behavior of participants during the experiment. The eye-tracker included two IR-sensitive CMOS cameras to record the scene and eye. An off-axis infrared illuminators was used to illuminate the participant's eye. The Positive Science eye-tracker was connected to a MacBook Air. Eye-tracking videos were analyzed with Positive Science Yarbus version 2.2.6 to determine where participants were looking. Semanticcode software version 2.0.1.5 was then used to generate fixations as well as code where participants were looking during each fixation for later analysis.

Procedure

Participants were welcomed to the experimental room and made comfortable. Participants were then given informed consent and demographic forms (Appendix A) and provided the opportunity to ask any questions. Before beginning the experiment participants were screened for color blindness using the Dvorine Pseudo-Isochromatic Plates. Participants who were able to identify as many 13 as of the 15 plates were considered to have normal color vision. It should be noted that one participant was unable to identify seven color plates, indicating moderate color deficiency. This participant was included in the final analysis because they were able to complete the experimental tasks and indicated they could see road signs and traffic lights. Participants then viewed a minute and thirty seconds of driving video filmed in a rural environment with no HUD display. This was done so participants could familiarize themselves with the experimental stimuli.

After viewing the practice video participants were asked to find a comfortable position which they could maintain for the next ten to fifteen minutes. The eye-tracker was put on. The experimenter then ensured the viewing distance was 57.3 cm. Participants were then read instructions for the eye-tracking calibration (Appendix B). The eye-tracker was then calibrated using a 9 point calibration on a grey background (set to the average of the pixels of the video) (Figure 5).

After calibration participants were read the instructions for the attentional conspicuity (Appendix C) portion of the experiment. Participants were asked to attend to the road environment as they would if they were driving vehicle that the video was shot from and to

verbalize what items attracted their attention (Charlton, 2006). The verbal responses were recorded by a GoPro4 camera placed behind the participant to the right. This position allowed for recording of the verbal response and the items on screen. At the completion of the attentional conspicuity portion of the experiment participants were read instructions for and then viewed a 5 point eye-tracking validation video (Appendix D). Once the eye-tracking was validated, participants were then given a sign recognition test (Appendix E or F). Participants were instructed to circle signs on a sheet that they had recognized from the previous video. The sheet contained 18 different signs, 9 of which were present in the video they had just watched.



Figure 5. 9-Point calibration stimuli. During actual calibration, a single fixation cross was visible to the participant for three seconds. After three seconds another fixation cross appeared in a random location until all nine crosses had been displayed.

Before the second part of the experiment the eye-tracker was calibrated for a second time using a 9 point calibration on a grey background (set to the average of the pixels of the video).

After calibration participants were read instructions for the Situation Awareness part of the

experiment (Appendix G). Participants were told they would be engaged in a casual conversation with the experimenter where they would be asked questions. Participants were instructed to answer the questions (Appendix H) as best as they could while continuing to watch the video screen. Having participants who are viewing driving videos engage in a casual conversation has been shown as a valid method to increase the mental workload of participants who are not engaged in an actual driving task (McCarley, Vais, Pringle, Kramer, Irwin, & Strayer, 2004). At the completion of the situation awareness portion of the experiment participants viewed a 5 point eye-tracking validation video. After the eye-tracking was validated the participants were then given the SAGAT questionnaire (Appendix I or J).

After the SAGAT questionnaire was administered participants were questioned about the surprise event where a pedestrian crossed the street at non cross walk location. To determine if participants noticed the surprise event they were asked if they noticed anything unusual during any of the video clips in reference to the pedestrian crossing the street at a mid-block location. The participant was asked progressively more specific questions to determine if they had noticed the surprise event. If the participant did not remember seeing or did not see the surprise event they were eventually informed and shown what they missed during the debrief (Appendix K).

At the completion of the Surprise Event Questionnaire participants were then asked if they recognized the any of the roads where the experimental video was filmed (Appendix L). Participants were then debriefed by the experimenter and given the opportunity to ask any questions related to the study.

The order of high and low clutter driving scenes was alternated between participants to account for order effects in the same way as it was done in the attentional conspicuity condition. Experimental conditions and order can be seen in Table 2

Table 2. Experimental conditions and order.

Condition	IV #1 Display Type	IV #2 Clutter	DV #1	IV #1 Display Type	IV #2 Clutter	DV #2
1	HUD	High Clutter	Attentional Conspicuity	HUD	Low Clutter	SAGAT
2	HUD	Low Clutter	Attentional Conspicuity	HUD	High Clutter	SAGAT
3	No HUD	High Clutter	Attentional Conspicuity	No HUD	Low Clutter	SAGAT
4	No HUD	Low Clutter	Attentional Conspicuity	No HUD	High Clutter	SAGAT

Results

Attentional Conspicuity

Figure 6 displays the average number of items noticed in the by drivers broken down by display type and driving environments. A two-way ANOVA revealed no significant interaction between display type and clutter, $F(1,32) < 1$. There was no significant main effect of display type, $F(1, 32) < 1$ or driving environment, $F(1, 32) = 3.02, p = .09$ on the total number of items noticed by drivers. Display type and driving environment had no effect on the number of items noticed by participants. Figure 7 displays all of the items participants noticed broken down by item type. There are separate bar graphs are broken down by display type.

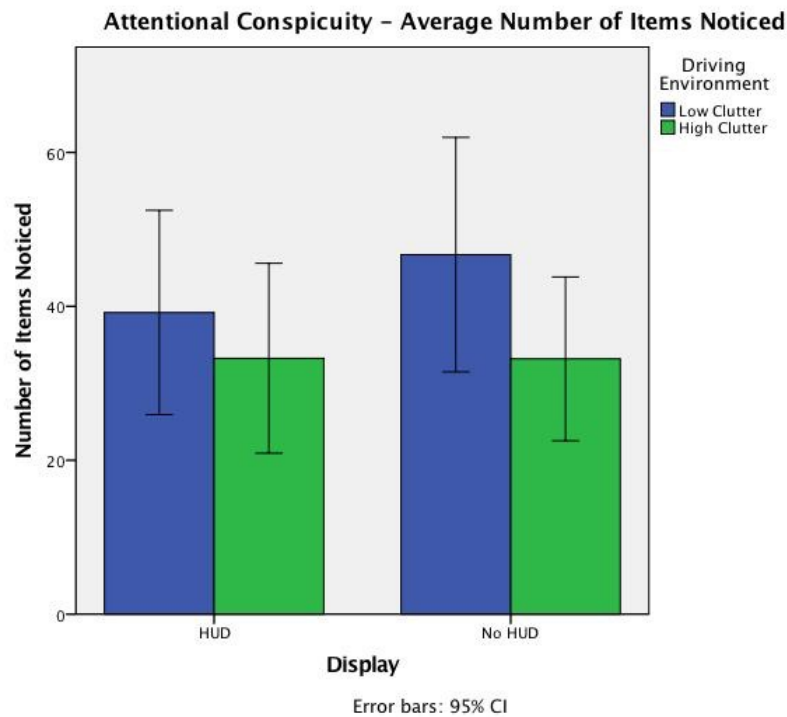


Figure 6. Bar graph displays mean number of items noticed by drivers, broken down by display condition and driving environment.

Figure 8 displays the average number of warning signs noticed by drivers broken down by display type and driving environments. A two-way ANOVA showed there to be no significant interaction between display type and clutter on the number of warning signs drivers noticed, $F(1,32) < 1$. There was also no significant main effect of display type $F(1, 32) = 2.23, p = .15$ and driving environment, $F(1, 32) < 1$ on the number of warning signs drivers noticed. Display type and driving environment had no effect on the number of warning signs noticed by participants.

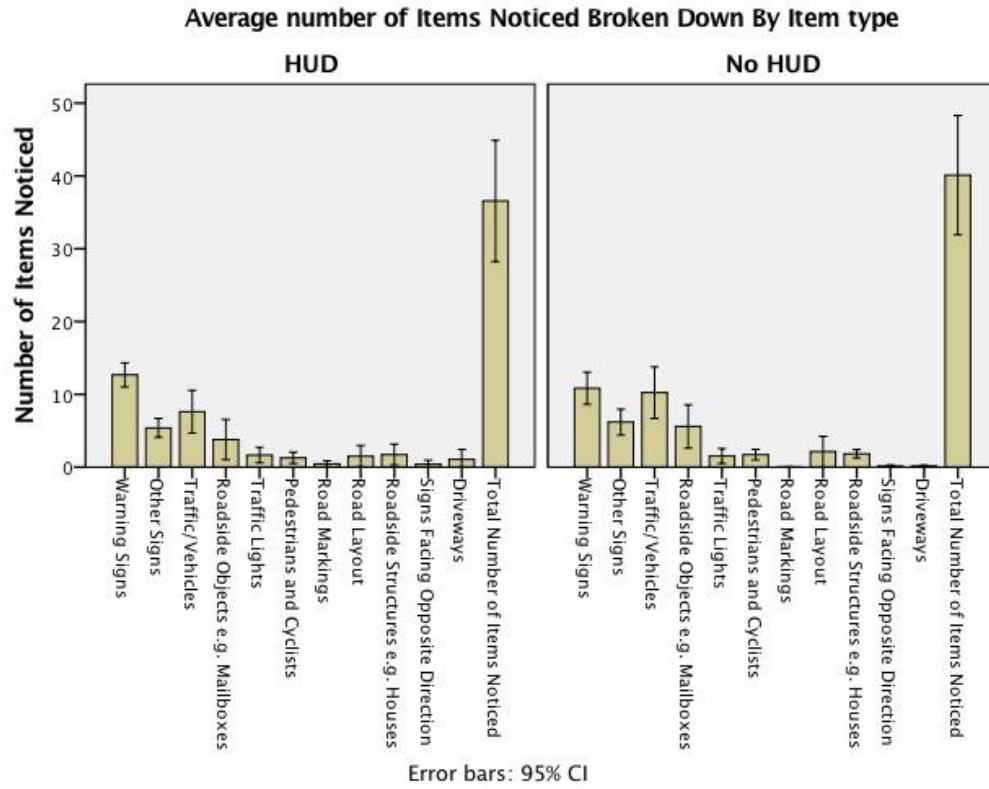


Figure 7. Bar graph displays the average number of all items noticed by drivers. Separate graphs for HUD and No HUD.

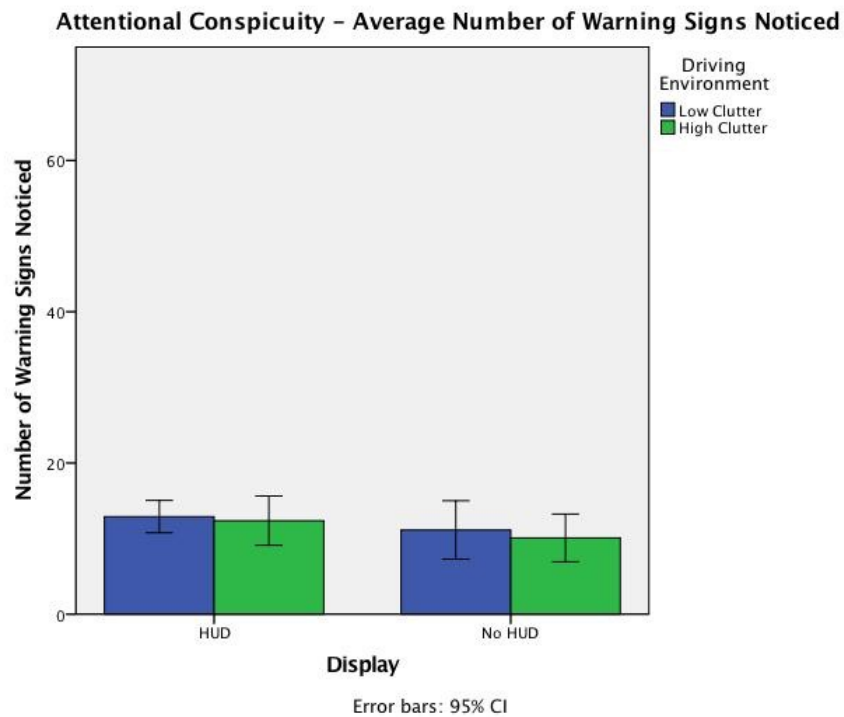


Figure 8. Bar graph displays average number of warning signs noticed by drivers, broken down by display condition and driving environment.

On average warning signs made up 39.9% of items noticed for drivers with a HUD compared to 29.1% of all items noticed for drivers without a HUD. Figure 9 displays the average proportion of all items that were noticed by drivers that were warning signs broken down by display type and driving environment. There was a significant main effect of display type on the percentage of warning signs that were noticed by drivers, $F(1,32) = 7.57 p = .01$. There was no significant main effect of driving environment on the number of warning signs noticed $F(1, 32) = 2.44, p = .13$. Display type had an effect on the proportion of items that were noticed that were warning signs but driving environment did not.

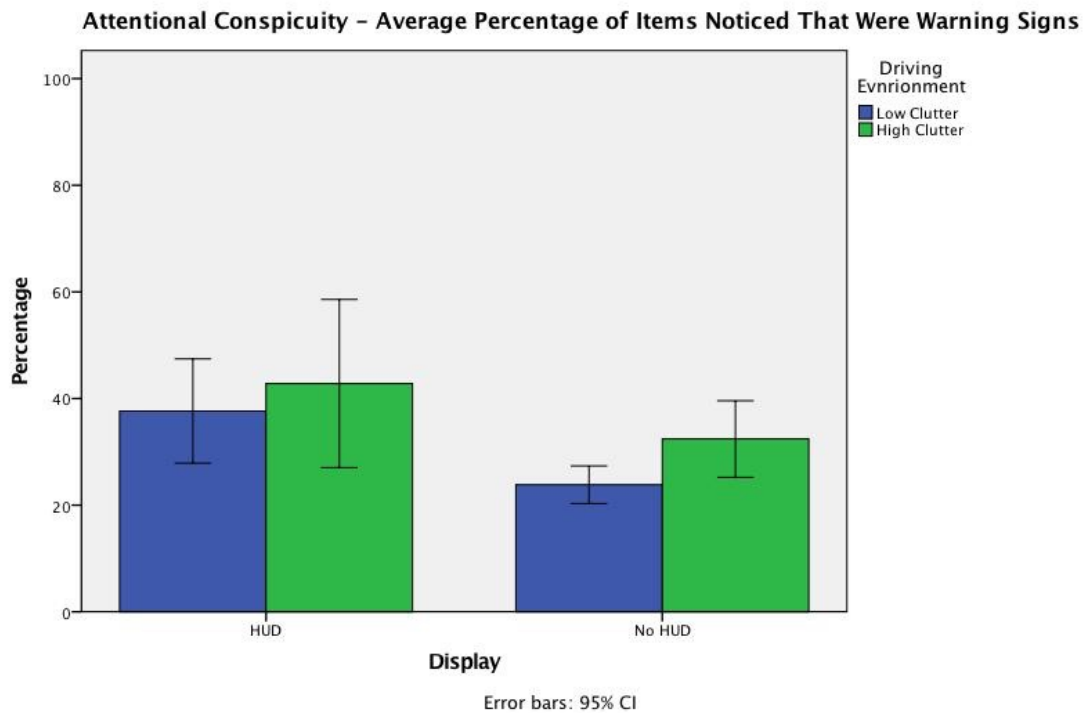


Figure 9. Bar graph displays average percentage of all items noticed that were warning signs. Graph is broken down by display condition and driving environment.

Sign Recognition

Average sign recognition results can be seen in Figure 10. A two-way ANOVA revealed no significant interaction between display type and driving environment on the ability of drivers to recognize signs $F(1,33) = 1.71, p = .2$. There was also no significant main effect of display type, $F(1,33) = 2.27, p = .14$, of clutter, $F(1,33) < 1$, on the ability of drivers to recognize signs. Display type and driving environment had no effect on the recognition memory of participants .

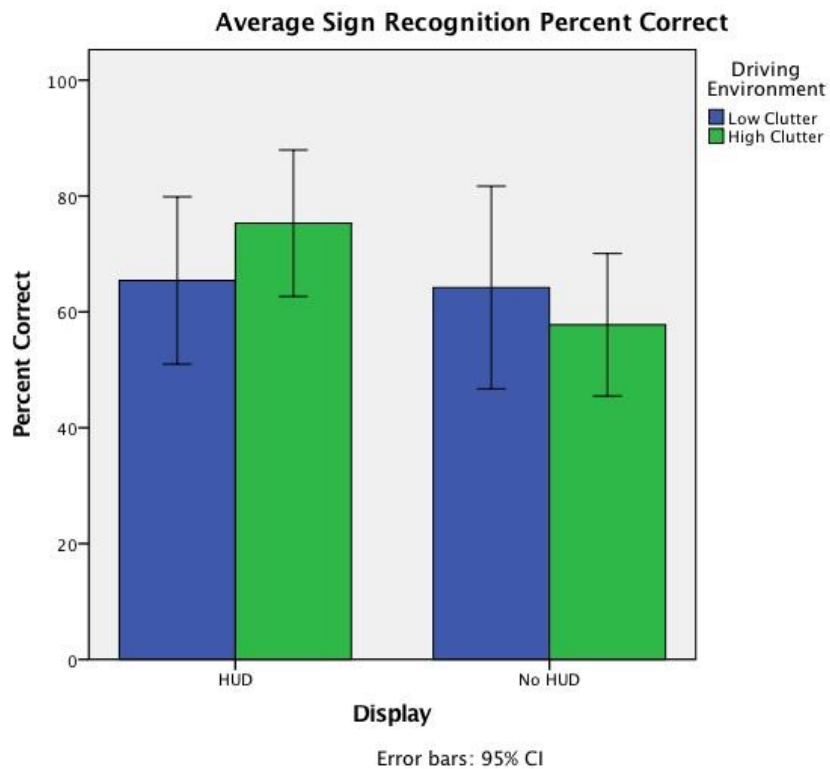


Figure 10. Bar graph displays average percentage percent correct on warning signs recognition test. Graph is broken down by display condition and driving environment.

Situation Awareness

Average SAGAT scores broken down by display and driving environment can be seen in Figures 11a-d. A two-way ANOVA revealed no significant interaction between display type and driving environment on overall SAGAT scores $F(1, 33) < 1$. There was no effect of display $F(1, 33) = .04, p = .84$, or environment $F(1, 33) < 1$, on the situation awareness of drivers. Display type and driving environment had no effect on the Situation Awareness of participants.

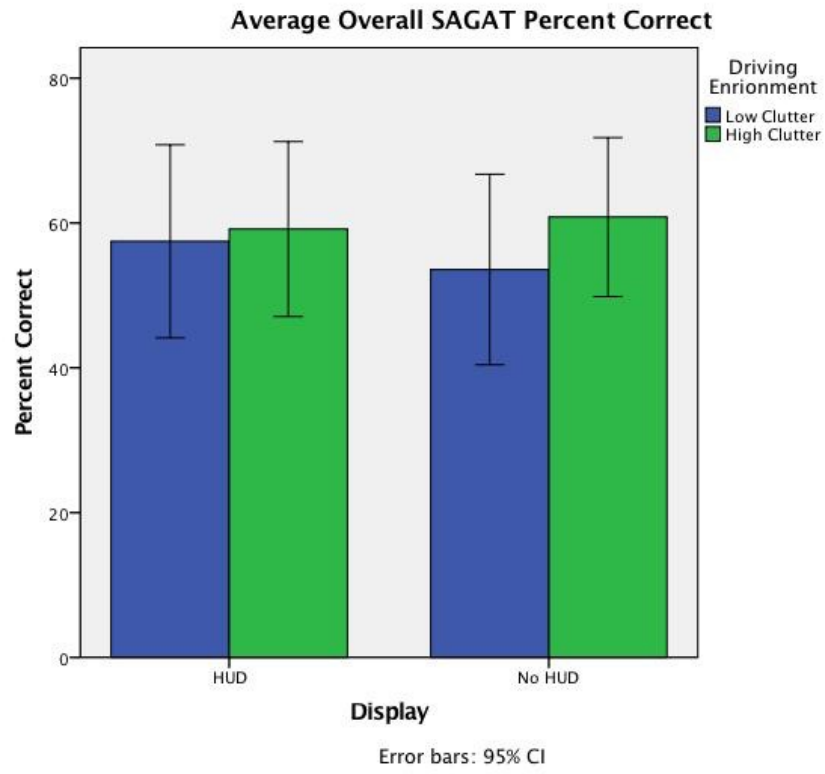


Figure 11a. Average overall SAGAT percent correct score.

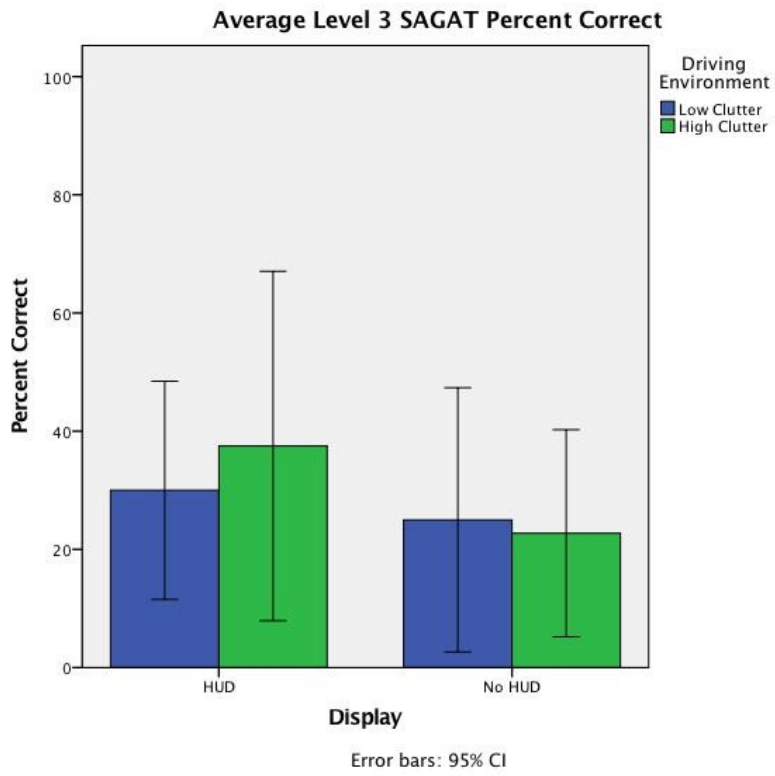


Figure 11b. Average SAGAT percent correct score for level 3 SA.

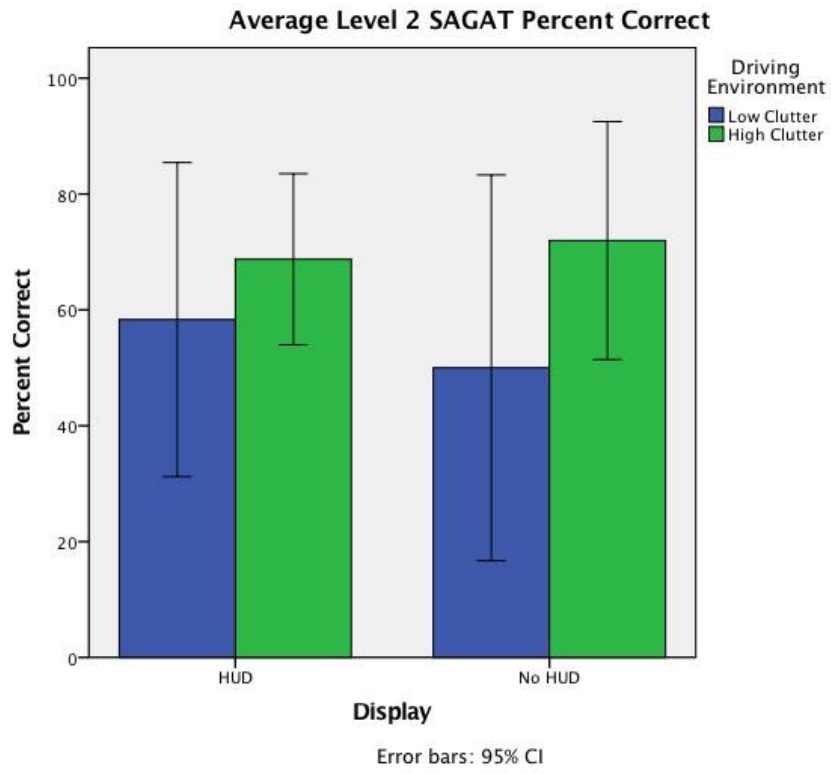


Figure 11c. Average SAGAT percent correct scores level 2 SA.

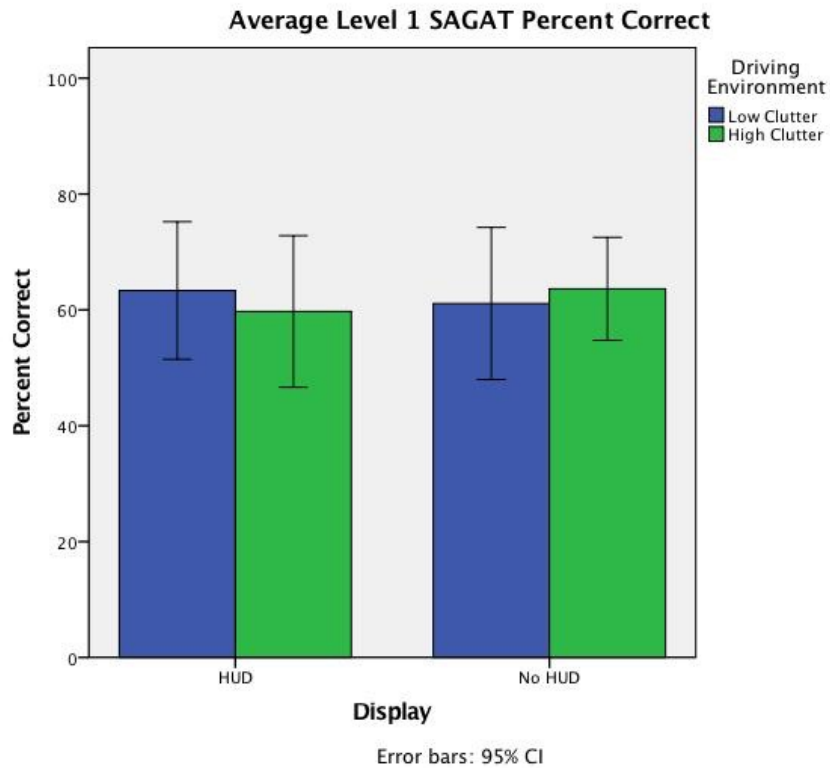


Figure 11d. Average SAGAT percent correct scores level 1 SA.

Surprise Event

When analyzing the surprise event data, participant responses were put into two categories; noticing the surprise event or not noticing the surprise event. For the purposes of the analysis the AR HUD group had 12 participants who noticed the surprise event and five who missed it. The no HUD group had 14 participants who noticed the event and five who missed it. A Chi-Squared test revealed no significant relationship between display type and how many drivers missed the surprise event, $\chi^2 (1, N = 38) < 1$. The results to the surprise event of the pedestrian crossing the street can be seen in Table 3. Display type had no effect on the ability of participants to detect a surprise event.

Table 3.

	Initial Probe	Second Probe	Final Probe	Missed Pedestrian	Total
AR HUD	6	7	1	5	19
No-HUD	10	2	2	5	19

Table 3. Results from surprise event probe broken down by display type.

Eye-Tracking Results

For all eye-tracking data a five second window of time was analyzed, encompassing the second before a sign was displayed in the HUD, the three seconds it was displayed in the HUD and the second after it was not visible in the HUD. Fixation duration is defined as the amount of time in ms that participants looked at a warning sign or the surprise event for 100 ms or greater. Previous research suggest that drivers can extract information from road signs is as little as 100 ms (Costa, Simone, Vignali, Lantieri, Bucci & Dondi, 2014) which is why this was the criterion chosen for a fixation in this study. Fixation frequency is defined as the number of instances when drivers looked to warning signs or the surprise event for more than 100 ms. The total fixation time can be defined as the sum of all individual fixation durations to warning signs or the surprise event.

Of the 38 participants in this study, 14 had usable eye-tracking data based on calibration data and eye-tracking video output. (Participants who had output with shaky or intermittent pupil tracks and/or output video where the scene camera had cut off a part of the experimental video were not used). There was a good amount of variability in the eye-tracking data as can be seen in the error bars located in bar graphs below (figures 13 through 18). Figures 12a through 12d

display frequency histograms for each display type and each driving environment. Even though there are outliers in each histogram, the majority of fixation durations are less than 1 second (1000ms) long and many are less than half a second (500ms).

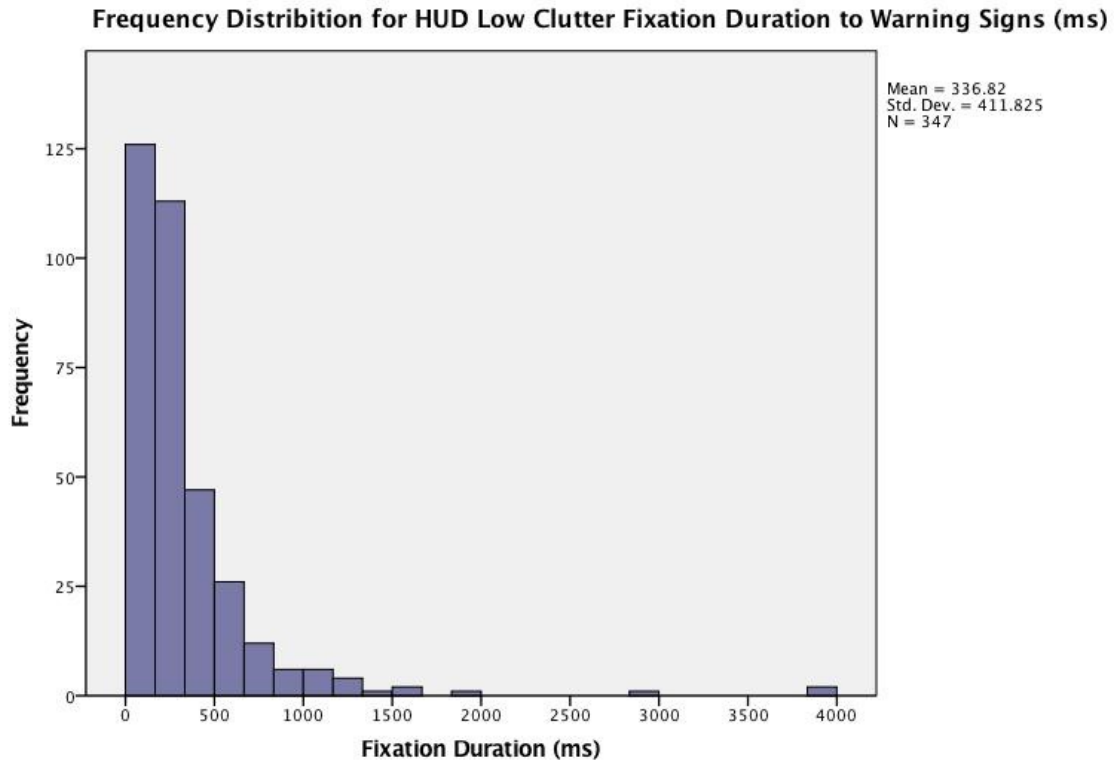


Figure 12a. Frequency distribution for fixation duration for participants with a HUD in low clutter driving environments.

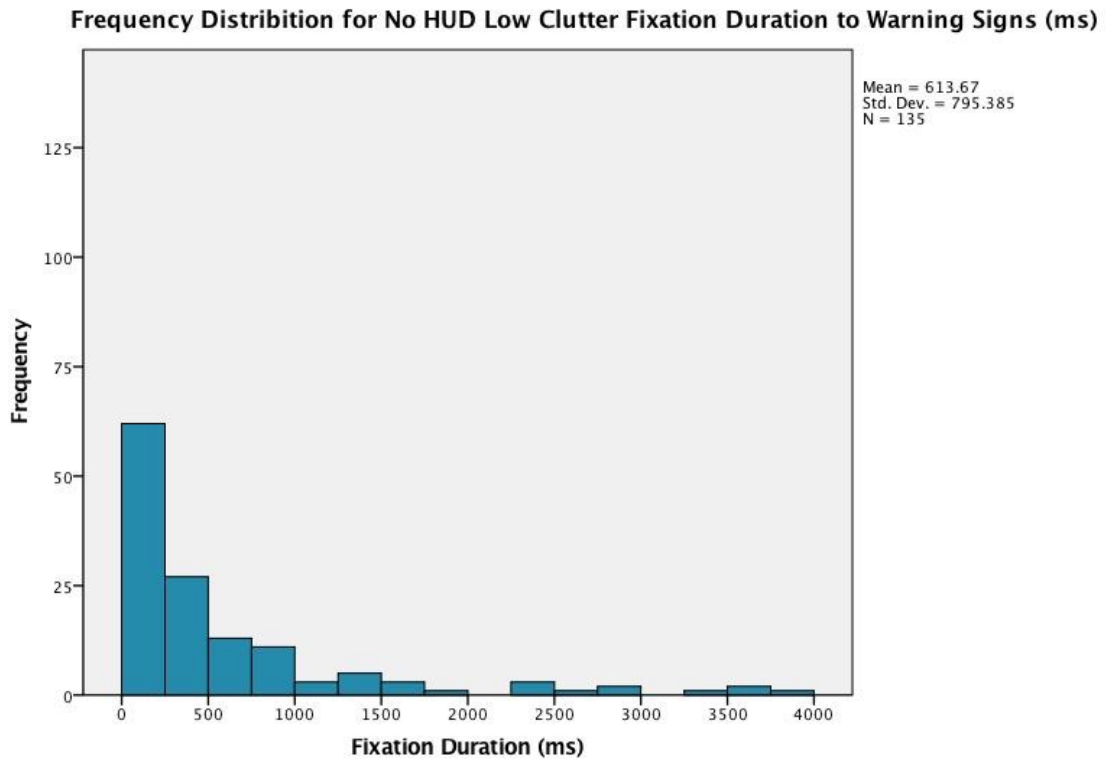


Figure 12b. Frequency distribution for fixation duration for participants with No HUD in low clutter driving environments.

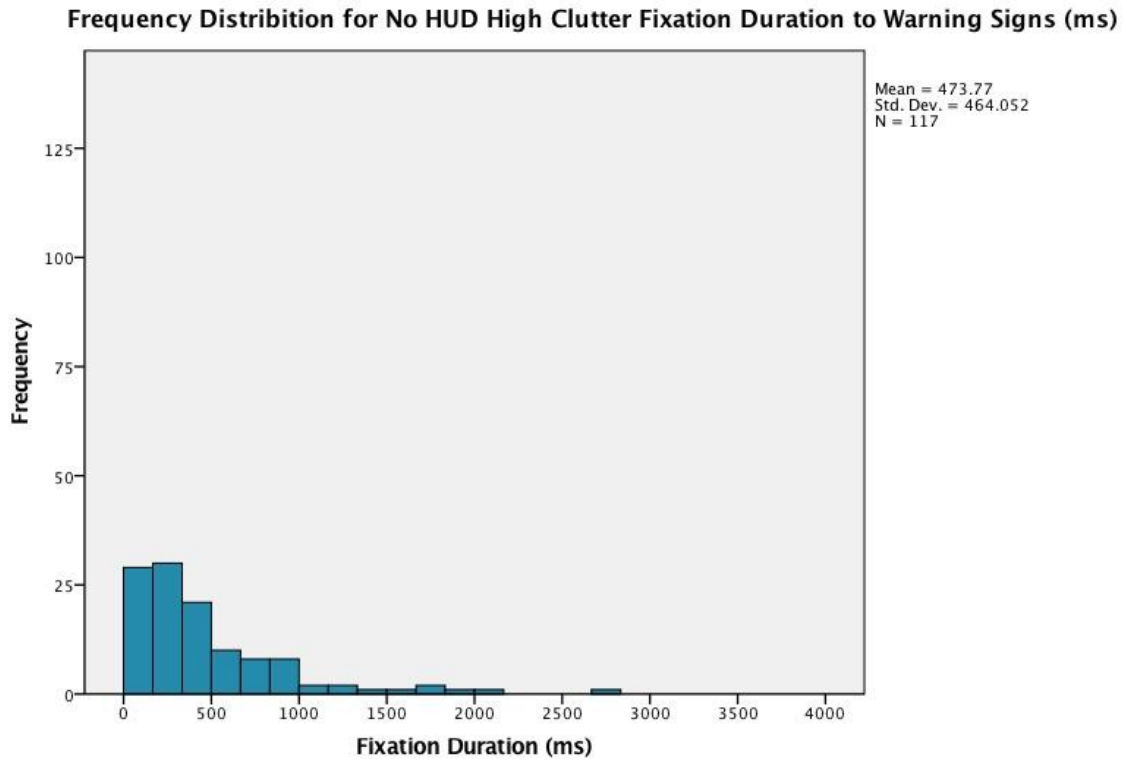


Figure 12c. Frequency distribution for fixation duration for participants with a HUD in high clutter driving environments.

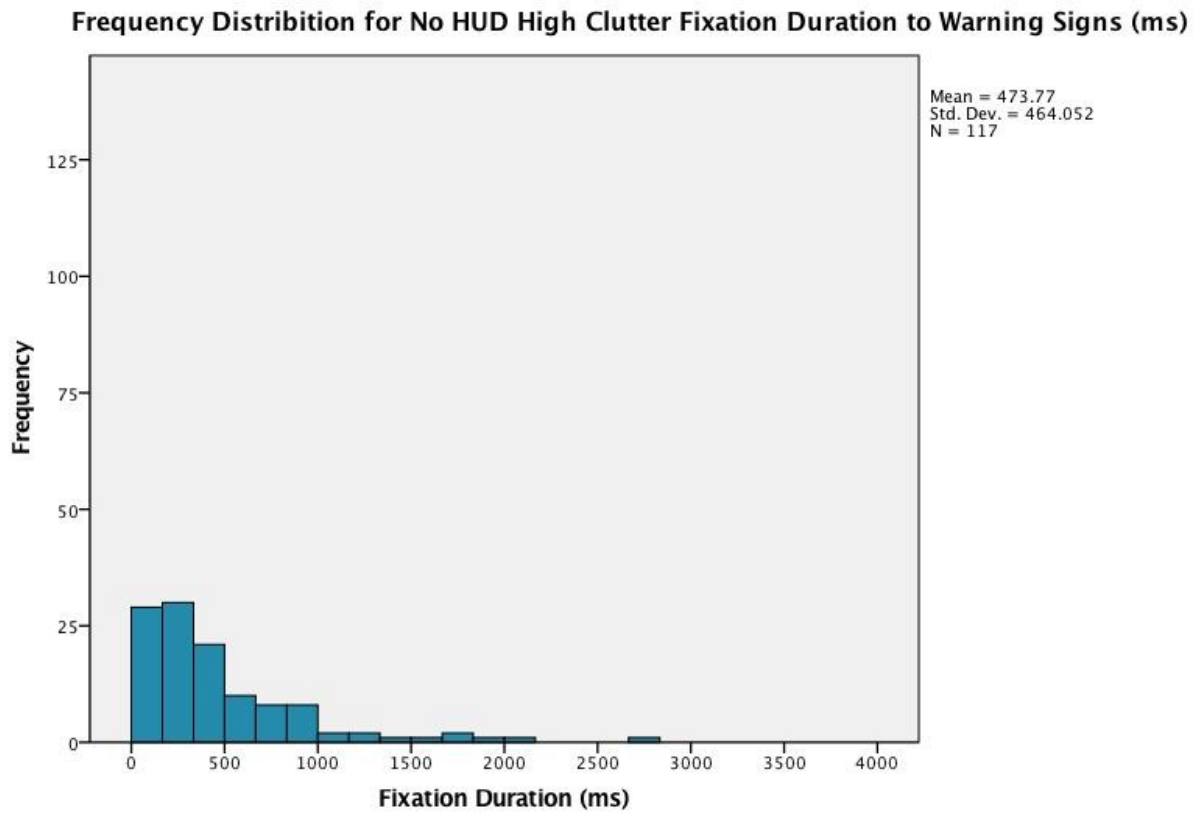


Figure 12d. Frequency distribution for fixation duration for participants with a HUD in high clutter driving environments.

Average fixation duration to warning signs for the attentional conspicuity portion of the can be seen in Figure 13. A two-way ANOVA showed there was no significant interaction between display type and driving environment $F(1,10) < 1$ on the amount of time drivers looked at warning signs. There was no main effect of display $F(1,10) < 1$, or clutter $F(1,10) < 1$, on the average fixation duration to warning signs. Display type and driving environment have no effect on participants fixation durations to warning signs.

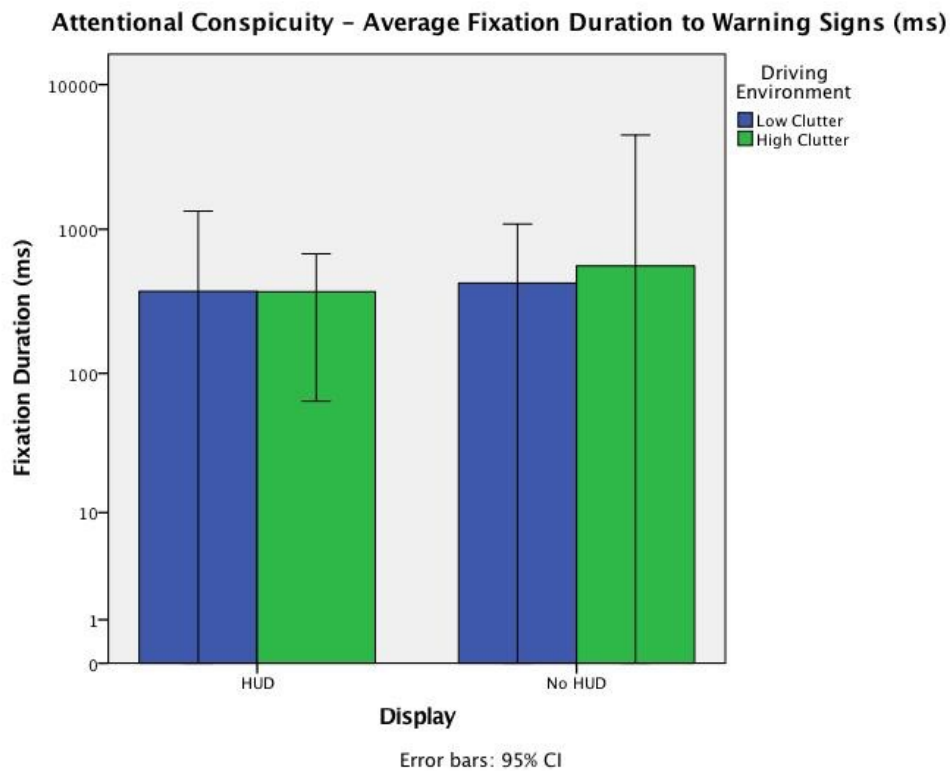


Figure 13. Bar graph displays average fixation duration to warning signs during the attentional conspicuity portion of the experiment broken down by display condition and driving environment.

Figure 14 displays the average number of fixations drivers made to warning signs. A two-way ANOVA showed there to be no significant interaction between display type and environment on the number of fixations drivers made to warning signs, $F(1,10) < 1$. There was no significant main effect of display type, $F(1,10) = 1.38, p = .27$ or clutter, $F(1,10) < 1$ on the number of fixations drivers made to signs. Display type and driving environment had no effect on the number of fixations participants made to warning signs

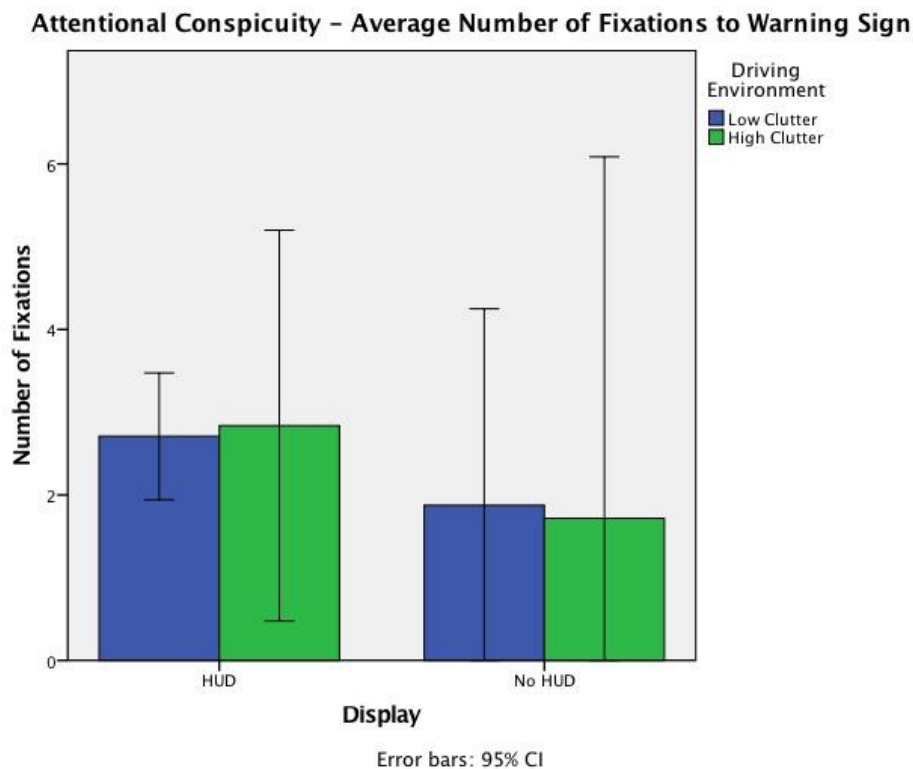


Figure 14. Bar graph displays average number of fixations drivers made to warning signs during the attentional conspicuity portion of the study. Graph is broken down by display condition and driving environment.

During the second portion of the study participants were instructed to watch the driving video as they normally would while engaged in a conversation with the experimenter. Average

fixation durations to warning signs can be seen in Figure 15. A two-way ANOVA revealed that there was no significant interaction between display type and clutter, $F(1,8) = 3.66, p = .09$.

There was no main effect of display type on average fixation duration to warning signs, $F(1,8) < 1, p = .54$. There was no main effect of environment on fixation duration to warning signs, $F(1,8) < 1, p = .97$. Display type and driving environment had no effect on participants fixation durations to warning signs.

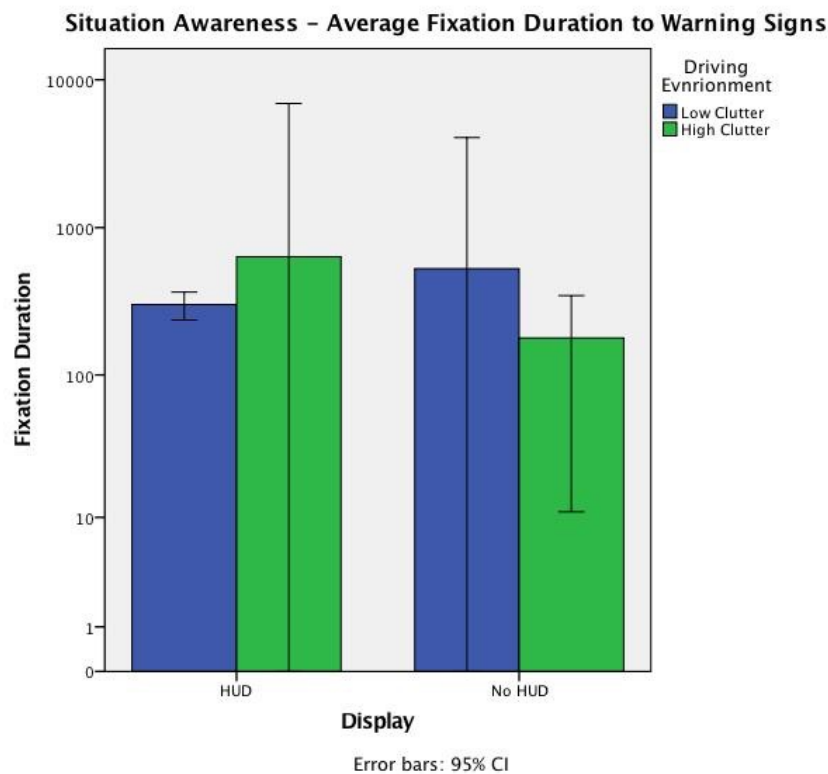


Figure 15. Bar graph displays average fixation duration during the SAGAT part of the study to warning signs. Graph is broken down by display condition and driving environment.

Figure 16 displays the average number of fixations drivers made to warning signs. Overall drivers without a HUD made 1.2 fixations (S.D. = .4) to warning signs. A two-way ANOVA did not reveal as significant interaction between display type and clutter, $F(1,8) = 1.75$, $p = .22$. Drivers with an AR HUD made an average of 2.8 fixations (S.D. = .62) to warning signs and drivers with no HUD made an average of 1.2 fixations (S.D. = .4) to warning signs. There was a main effect of display type on the number of fixations drivers made to warning signs, $F(1,8) = 31.2$, $p = .01$. There was no main effect of clutter on the number of fixations drivers made to warning signs $F(1,8) < 1$, $p = .40$. Driving environment had no effect on the number of fixations participants made to warning signs but an AR HUD increased the number of fixations made by participants.

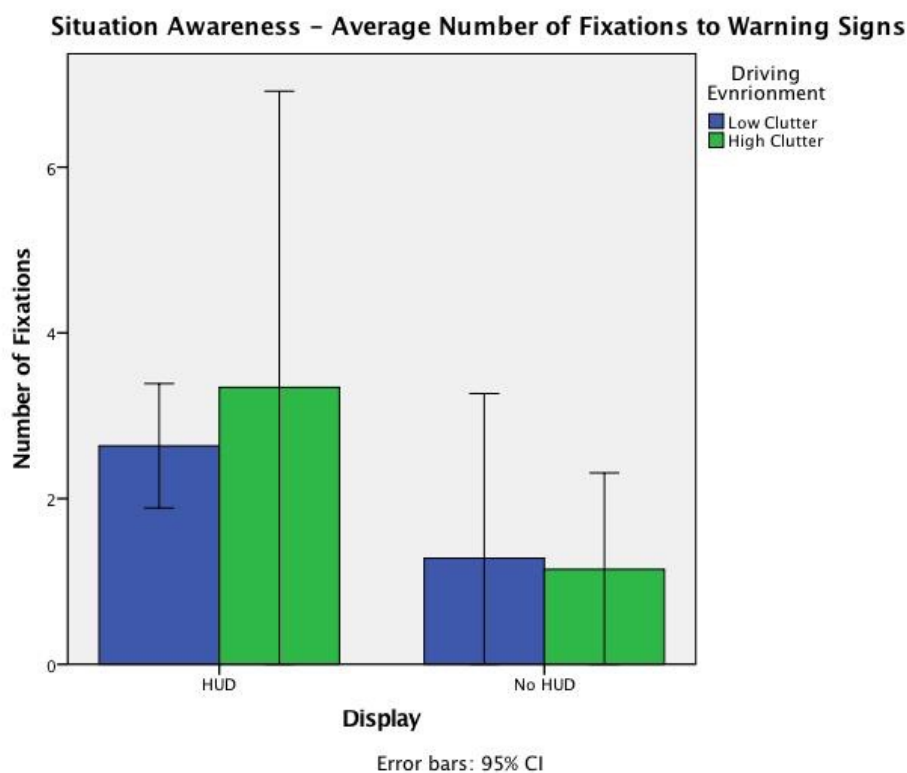


Figure 16. Bar graph displays average number of fixations to warning signs. Graph is broken down by display condition and driving environment.

Figure 17 displays the average fixation duration to the surprise event. A two-way ANOVA revealed no significant interaction between display type and clutter $F(1,8) < 1$ and no main effect of display, $F(1,8) < 1$ or environment type, $F(1,8) < 1$ on the time drivers spent looking at the surprise event. Display type and driving environment had no effect on participants' fixation durations to the surprise event.

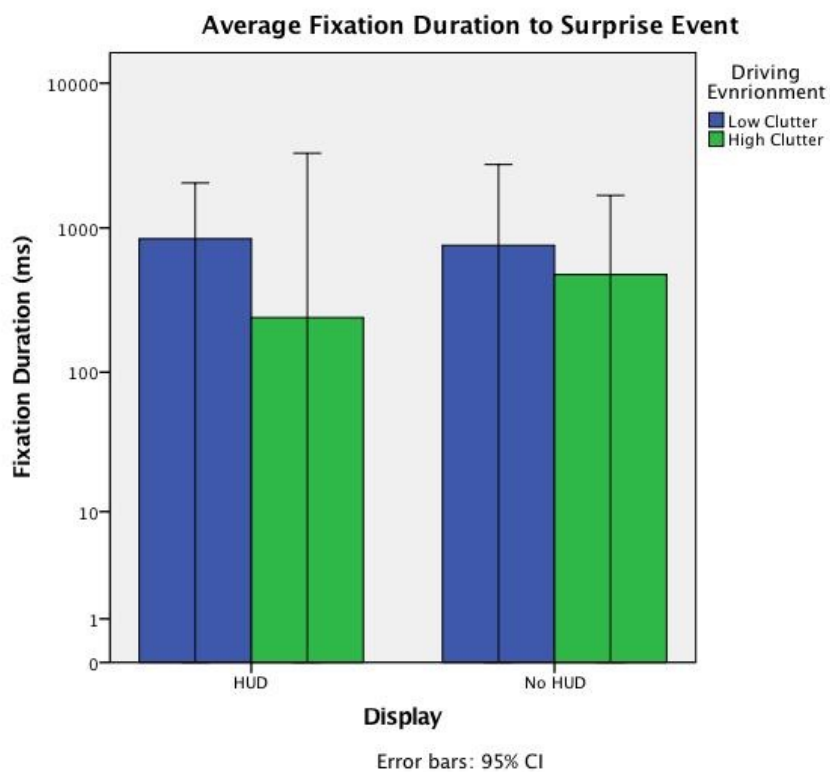


Figure 17. Bar graph displays average fixation duration to the surprise event. Graph is broken down by display condition and driving environment.

Figure 18 displays the average number of fixations to the surprise event. A two-way ANOVA showed no significant interaction between display and environment clutter, $F(1,8) = 1.6, p = .26$. There was no main effect of display, $F(1,8) < 1$, or clutter on the number of

fixations to the pedestrian during the surprise event, $F(1,8) < 1$. Display type and driving environment have no effect on the number of fixations participants made to warning signs.

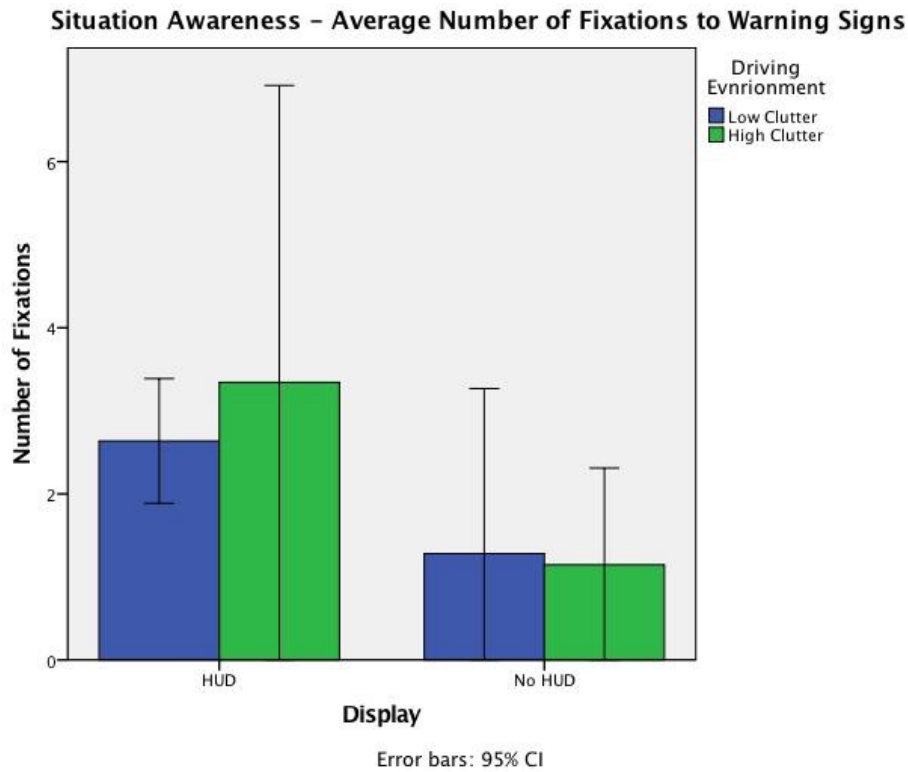


Figure 18. Bar graph displays average number of fixations to the surprise event. Graph is broken down by display condition and driving environment.

To evaluate how drivers allocated attention when both warning signs and other vehicles were in view, the average percentage of time (5 second) drivers looked at warning signs and cars within 5 second windows of interest were compared between display type. When two driving related items such as a car and a warning sign are visible to drivers it is necessary to see how display type influences how drivers allocate their attention. Table 4 displays the average percent of time participants spent looking at cars or signs when they had to make a choice between the two and whether or not they display type significantly impacted looking times.

Table 4. Video - AC Low Clutter					
	Number of times where sign and care are visible	Display	Mean	S.D.	Significance
Percentage of time looking at sign	5	HUD	15.6	8.5	N.S.
		No-HUD	15.6	10.4	
Percentage of time looking at car	5	HUD	20.9	14.6	N.S.
		No-HUD	22.7	10	
Video - Low Clutter SAGAT					
	Number of occasions where a conflict occurs	Display	Mean	S.D.	Significance
Percentage of time looking at sign	7	HUD	11.9	9.5	N.S.
		No-HUD	13.4	10.9	
Percentage of time looking at car	7	HUD	21.1	10	N.S.
		No-HUD	19.3	12.2	
Video - AC High Clutter					
	Number of occasions where a conflict occurs	Display	Mean	S.D.	Significance
Percentage of time looking at sign	12	HUD	16.1	9.1	N.S.
		No-HUD	21.7	14.9	
Percentage of time looking at car	12	HUD	13.8	11	N.S.
		No-HUD	17.5	8.5	
Video - High Clutter SAGAT					
	Number of occasions where a conflict occurs	Display	Mean	S.D.	Significance
Percentage of time looking at sign	13	HUD	23.5	7.3	$p < .001$
		No-HUD	5.5	4.2	
Percentage of time looking at car	13	HUD	5.2	7.3	$p < .05$
		No-HUD	13.5	7.3	

During the SAGAT part of the study in high clutter environments where drivers need to decide to look at warning signs or cars, drivers with the AR HUD look at signs approximately 24% of the 5 second window of interest, and with no HUD about 6% of time looking at signs. Drivers with an AR HUD who spend significantly more time looking at signs than drivers with no HUD, $t(24) = 7.73$, $p < .001$. During high clutter SAGAT videos, drivers with a HUD spent approximately 5% of the time window of interest looking at cars compared to drivers with no HUD who spend 13% of their time looking at cars. These differences are statistically significant, $t(24) = 2.96$, $p = .008$. In low clutter driving situations display type did not influence the proportion of time drivers spent looking at cars in situations where both cars and signs were visible to drivers.

Discussion

Accidents are caused by drivers who fail to perceive important elements in the driving environment, do not understand how these elements interact with each other, and/or are unable predict what will happen in the near future (Endsley, 1995a). In short, unsafe drivers lack SA. The goal of this study was to investigate how an AR HUD affects drivers attention and SA. A secondary goal of this study was to determine how driving environment affects drivers attention and SA. To answer these research questions self report and eye-tracking methodologies were used.

In the first part of the experiment, while watching videos of driving scenes participants were asked to report what items captured their attention. This method was used by Charlton

(2006) when investigating how drivers attend to signs. During this portion of the experiment drivers with the AR HUD noticed no fewer items than drivers without a HUD display. This result suggests an AR HUD may alter drivers' schema in low clutter driving environments but not to the point where they only attend to a certain area of the environment or experience attentional tunneling (Turfano, 1997). If drivers would have only noticed warning signs or a limited number of objects in the AR HUD condition that would have indicated attentional tunneling.

It is possible that the perception of warning signs can contribute to a high level of driver SA. Warning signs are intended to provide information to drivers about future road conditions and allow them to choose safe driving behavior (Castro & Horberry, 2004). An AR HUD is intended to highlight relevant driving information (Gabbard, et al., 2014) and therefore may allow drivers to develop a high level of SA. Of all items that drivers noticed in the attentional conspicuity portion of the experiment, warning signs accounted for a significantly larger portion of items for drivers with an AR HUD compared to drivers with no HUD. Driving environment did not make a significant difference in the number of items noticed or the proportion of items that were noticed that were warning signs. This result provides strong evidence that warning signs presented in a HUD are conspicuous and capture attention. The HUD appears to alter drivers' normal attentional deployment patterns when explicitly instructed to report what items are attentionally conspicuous. The fact that warning signs made up a greater percentage of items noticed for drivers with the HUD than drivers without means that warning signs presented via a HUD are more salient to drivers than they would be without an HUD. Considering these results within the SEEV model it is clear that a HUD is effective in aiding in visual search by increasing

the saliency and apparent value of warning signs displayed (Wickens et al., 2013). If drivers are conscious of the warning signs or they attract more attention, they may begin to process the information contained in the warning sign earlier and more often allowing them to be better prepared for upcoming road conditions, leading to a higher level of SA. Although the HUD led to a greater proportion of warning signs being noticed, it did not lead to an overall greater number of warning signs being noticed. This result may indicate that the HUD only had a small effect on altering the attentional schemas of drivers.

Along with self-report data, eye-tracking data tell a story about where drivers attend. Although drivers with a HUD reported noticing more warning signs in the attentional conspicuity portion of the study, there was no significant difference in the number of fixations to or the average fixation duration to warning signs in the second part of the study where drivers were viewing videos under more natural attentional conditions. Based on the number of signs reported in the attentional conspicuity part of the study it seems as though drivers who have an AR HUD may process warning signs differently than drivers without a HUD even though there was no difference in the duration or number of times drivers looked at warning signs. This may mean that in the same amount of time drivers can look at signs they will recognize, remember and process signs as efficiently as drivers without a HUD. This conclusion was reached because drivers with a HUD report more warning signs than drivers without a HUD. This is possible evidence that presenting warning signs via an HUD may initiate the process of level 1 SA (perception) which is the basis for all other levels of SA (Endsley, 1995a). Drivers with an AR HUD may have the potential for better level 1 SA than drivers without a HUD, because they are more aware of warning signs. This conclusion should be taken with caution as drivers in the

attentional conspicuity portion were asked to name items that were attentionally conspicuous, possibly biasing them to alter their visual and attentional patterns in an unnatural way compared to drivers who do not receive special viewing instructions. During the second half of the study, while viewing videos participants were engaged in a casual conversation with the experimenter. This was intended to increase the workload of participants to the level closer to what is experienced when actually driving a vehicle (McCarley et al., 2004). When viewing driving scenes under more natural attentional control, display and driving environment had no effect on the number and duration of fixations drivers made to warning signs. This result is another piece of evidence that in simple driving situations, HUDs do not negatively affect drivers' attention. Drivers were able to follow habitual attentional deployment patterns, letting their experience and driving goals guide where they look, not looking to warning signs in the display for a significantly longer amount of time than drivers without a HUD.

A potential drawback of HUDs is they may negatively affect a drivers's attention to the point where they miss an atypical or surprise event such as a person crossing the street at an unexpected location. In both the HUD and no HUD groups, five participants missed seeing the surprise event of the pedestrian crossing the street. Display type and driving environment make no significant difference in the number of drivers who missed the event. Drivers with a HUD are no more likely than drivers with no HUD to miss unexpected events in the driving environment.

Up to this point it seems as if there are no negative effects of an AR HUD on driver's attention and they may increase the saliency of driving related items such as warning signs. In many situations a HUD may allow drivers to be more attentive to level 1 SA information compared to drivers without a HUD. Due to the complex and dynamic nature of the driving

environment there are many times when drivers need to decide between several alternatives as to where they direct visual attention to achieve a sufficient level of SA and safely navigate. To understand the visual behavior of drivers in more complex situations, five second windows of time where drivers had relevant driving information in sight (a warning sign and other vehicles) were evaluated. For the attentional conspicuity portion of the study drivers in both low and high clutter environments spent no different amounts of time looking at either warning signs or cars when both of them were visible within 5 second windows. Eye-tracking data revealed some interesting results for the second part of the study where drivers were under more natural attentional control and had to choose where to look. In the low clutter driving situation when a choice had to be made to look at signs or other vehicles, drivers in each display group did not spend different amounts of time looking at other vehicles and warning signs. It appeared that drivers alternated between reflexive attentional control, which is guided by environmental stimuli (the HUD) and habitual control which is guided by goals and past experience, to appropriately alternate between looking to signs and cars. However in high clutter situations when there was a choice between looking at other vehicles on the road or a warning sign, it appears drivers with an AR HUD were under reflexive attentional control, looking at salient warning signs in the HUD for a significantly longer proportion of the time compared to drivers with no HUD. Additionally drivers with an AR HUD spent significantly less time looking at cars than drivers with no HUD in situations where there was a choice between two relevant driving items. These results suggest that in high clutter or city driving environments, where drivers must process multiple stimuli simultaneously, they may not appropriately attend to objects in the environment and may spend an inappropriately long amount of time looking at

warning signs displayed in an AR HUD, revealing attentional tunneling. In high clutter or city driving situations where drivers need a high level of SA and a HUD could potentially be most beneficial, it appears to be detrimental. Drivers appeared to be under reflexive attentional control for an inappropriate amount of time. The ultimate goal of the HUD would be to have drivers evoke reflexive attention to attend to warning signs and then use the level 1 SA information acquired from warning signs to alter habitual attentional patterns to find more valuable information in the environment. Instead, it appeared that drivers focused on only the highlighted level 1 SA item (warning sign) and didn't look at other items such as cars.

One of the goals of this study was to measure how display type and display environment affected drivers' SA. SA was assessed using a SAGAT questionnaire developed for the driving situations of the study. Results indicated that display type and driving environment have no effect on the SA of drivers. Due to the fact that participants were involved in a task that was relatively passive in comparison to driving the results may not accurately represent the SA of participants. Because of the artificial nature of the simulation drivers may have lacked the motivation to be fully engaged in the experimental task. The main reason they may have lacked motivation was because there was no penalty or risk associated with having a low SA in this study. When actually driving, a possible penalty of low SA is an accident or injury. Therefore when driving real vehicle people have more motivation to properly attend to important areas of the driving environment.

In Charlton's (2006) study providing participants with different instructions to either look for conspicuous items or look for hazards and hazard warning signs was effective in adjusting habitual attentional deployment patterns and led the more warning signs being noticed in the

second condition. The present study showed that an AR HUD is enough to evoke reflexive attentional deployment and make participants attend to and increased proportion of warning signs compared to drivers without an HUD in part one of the study. However, in part two participants reflexive as well as habitual attention was affected. Participants when given the choice of two driving related pieces of attention looked to warning signs for a significantly longer amount of time as described above. Reflexive attentional control led participants with an AR HUD to look to warning signs more often and for an overall longer period of time in complex situations, and participants did not return to the habitual deployment of attention after looking at signs. It appears that the HUD icons in this study may have been too salient, not allowing drivers to process the level 1 SA information (signs) and then continue to normally attention to the environment and look at important information within view such as cars.

Limitations

Although this study provided some interesting findings on how display type and environment affect how drivers attend to their environment and develop situation awareness it is limited in some ways. The most obvious limitation was that participants were not driving a vehicle at any point in the study. If participants were driving a real vehicle (or simulator), how they attend to various locations in the driving environment may change and possibly alter use of the AR HUD. Because of the nature of this study, SA was difficult to assess. The SAGAT when used in the aviation domain asks pilots about their altitude, heading as well as speed (Endsley, 1995b). In this study objective questions about vehicle speed and direction could not be asked because participants did not have this information. This led to a combination of objective and

subjective questions being asked in the SAGAT and this constraint may have contributed to overall low SAGAT scores.

The surprise event in this current study occurred when there was nothing being displayed in the HUD. In future studies it would be interesting to see how drivers allocate attention between a HUD containing information such as warning signs and a surprise event such as a person crossing the street at an unexpected point in time. The results of this study suggest that in high clutter driving environments attentional tunneling occurs for drivers with an AR HUD when they need to allocate their attention across two different areas of interest. This result would lead one to predict that more drivers with a HUD would miss a surprise event if it were to occur at the same time an icon was visible in the HUD. A final limitation of this study was the highly salient nature of the HUD icon. The icons used were 100% opaque and had an abrupt onset which has been shown in laboratory experiments to immediately capture attention (Theeuwes, 1994). It is possible that different type of HUD icons may influence the results of this study. AR HUDs that outlines areas of interest or use transparent icons may lead to different results.

Implications and Future Directions

The results of this study suggest that in certain driving situations HUDs may help drivers properly allocate attention and develop a high level of SA. Automotive manufactures and developers of HUDs should consider designing displays that recognize the driving environment and present HUD elements at appropriate times which may mean not displaying HUD icons in some situations.

It would be beneficial for future studies that examine the effect of HUDs for warning signs on driver SA to either use a driving simulator or a real vehicle with a HUD capable of displaying the required information. It may be challenging to program a simulator to be able to display AR graphics over real world scenes but if a simulator could display the correct information valuable results could be obtained with regards to how driving behavior, rather than just perception is affected by a HUD for warning signs. Eventually research could also look into how driving behavior on real roads or a closed test track is affected by HUDs for warning signs. The safety of drivers would be the largest concern in on road studies, however another practical concern would be if computer and machine vision systems are currently advanced enough to be able to accurately and quickly detect road signs to allow a HUD to project them in sufficient time for drivers. Last, with the increase in automated features in vehicles and the possibility of full automation in the future, subsequent studies may examine how HUDs affect the overall SA of drivers of partially and fully automated vehicles. These studies may also assess driving behavior when the situation requires the driver to take over the vehicle control when automation is unable to handle the road conditions.

Conclusion

In simple situations where drivers have fewer decisions as to where they attend in the driving environment, a HUD appears to make warning signs more salient and attentionally conspicuous. When considering the visual behavior of drivers in simple driving situations, there also appears to be no effect of display type or driving environment on fixation duration or number of fixations to warning signs. However, in more complex and high clutter driving environments where drivers need to allocate attention to multiple areas of interest, participants

with a HUD may experience cognitive capture. Drivers with a HUD direct an unnecessarily large amount of visual attention to warning signs highlighted in the HUD. This type of cognitive capture may result in a lower level of SA and possibly lead to unsafe driving situations. The wide variety of situations encountered by drivers and the flexibility of displays in what and how they may be able to highlight areas of interest leave many opportunities for additional research into the effects of HUDs on driver attention and SA.

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Appendix A

Augmented Reality HUDs and Drivers' Situation Awareness - Demographic Questionnaire

1. Participant ID Number:
2. Age:
3. Sex: Male Female
4. Number of years with a full drivers licence:
5. Number of accidents in the past 5 years:
6. Do you have any driving experience with in-vehicle Head Up Displays: Yes No
7. If you answered yes to 6, please explain:

Appendix B

Eye Tracking Calibration Instructions

Before we begin the eye tracking machine needs to be calibrated to make sure it works correctly. Please find a comfortable position that you will be able to stay in for the next 10-15 minutes. The first video will contain black x's that will appear in a random place on the screen. When the x appears please focus on it until the next x appears on the screen.

Appendix C

Attentional Conspicuity Script

For this part of the experiment we are interested in what aspects of the driving environment capture your attention. Envision yourself as the driver of the vehicle in which the video is shot from. We would like you to survey the driving environment as you would if you were driving. As the video plays, please say out loud what items attract your attention. For example if a pedestrian attracts your attention, you can simply say "person in red coat". If markings on the road attract your attention you can say, "white stop line". If a red light attracts your attention say "red light". There are no right or wrong answers, and there is no need to censor yourself. Whatever objects attract you attention, simply say them out loud.

Do you understand what is being asked of you?

Do you have any questions?

Appendix D

Eye Tracking Validation Instructions

We now have to validate the eye-tracking data from the first part of study. The instructions are the same as the first calibration video from a few minutes ago, when a black x appears on the screen please focus on it until the next x appears.

Appendix E

Low Clutter Route Recognition Measure

Please circle the warning signs that were present along the route. (Correct answers are circled)



Appendix F

High Clutter Route Recognition Measure

Please circle the warning signs that were present along the route. (Correct answers are circled)



Appendix G

Situation Awareness Script

For this part of the experiment we ask you to envision yourself as the driver of the vehicle which video is shot from. We would like you to survey the driving environment as you would if you were the driving. As the video plays the experimenter will ask you some simple, casual questions. We ask that you answer the questions as best as possible while continuing to watch the driving video.

Do you understand what is being asked of you?

Do you have any questions?

Appendix H

Situation Awareness Script - Casual Conversation Questions

Experimenter instructions: These are a list of general questions that you can ask the participant while they are viewing the driving video.

Note: Please ensure that you keep your eyes on the screen when you are asking the questions so the participant knows they should be doing the same.

Do you watch any tv shows right now?

What is your favourite show?

What is it about?

Are you a sports fan?

What sports do you like?

Do you have any favourite teams?

What types of music do you like?

Do you have any favourite artists?

What other types of hobbies do you have?

Appendix I

Low Clutter SAGAT Questions

1. At the time the simulation was stopped how many lanes in each direction were there on the current road?
2. Was there a centre turning lane on the current road?
3. Was there a safe place to pass along the road, if so where was it?
4. At the point which the simulation was stopped, which way was the road curving?
5. What was the speed limit on the road when the simulation was stopped?
6. What were the traffic conditions on the current road?
7. Were there any pedestrians on the sidewalks along the route?
8. Where would be a safe place to pull over?
9. What was the most common hazard to be aware of along the route either indicated by warning signs or your own perceptions?
10. Did bikes have dedicated lanes along any point of the road?
11. What was the weather like?
12. Were there any wildlife hazards that you should be aware of?
13. Do these wildlife hazards have any implications for your future driving behavior?
14. Did you notice any roadside objects, if so what were they?
15. Do these roadside objects have any implications for your future driving behavior?

Appendix J

High Clutter SAGAT Questions

1. At the time the simulation was stopped how many lanes in each direction are there on the current road?
2. Was there a centre turning lane on the current road?
3. At the point which the simulation was stopped, which way was the road curving?
4. What was the speed limit on the road when the simulation was stopped?
5. What were the traffic conditions on the current road?
6. Were there any pedestrians on the sidewalks along the route?
7. Where would be a safe place to pull over?
8. What was the most common hazard to be aware of along the route either indicated by warning signs or your own perceptions?
9. Did bikes have dedicated lanes along any point of this road?
10. What was the weather like?
11. Were there any wildlife hazards that you should be aware of?
12. Do these wildlife hazards have any implications for your future driving behavior?
13. Did you notice any roadside objects, if so what were they?
14. Do these roadside objects have any implications for your future driving behavior?

Appendix K

Surprise Event Detection Questions

To be asked after participant views the final video.

- A. Did you notice anything out of the ordinary while you were watching the video? If so please describe what you noticed.
- B. Did you notice any pedestrians that were out of place in the video? If so please describe what you noticed.
- C. Did you notice a pedestrian cross the road at a location other than a cross walk?

If yes

- D. Please describe what this pedestrian was wearing and the location which they crossed the street.

Appendix L

Route Recognition Questions

Do you recognize the road where the video was shot?

Where was it?