Chetana Karande

Obstacle cuing in Augmented Reality Head Up Displays

Perceptual tunnelling and effect of cuing

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Master in Interaction Design
Submission date: June 2021
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Abstract

The use of Augmented Reality (AR) has increased over last decade. Now the applications are not limited just to the aviation industry and the military but are used in consumer market as well. A lot of research is being taken place in automobile industry. Latest development is use of AR on Head-up Displays inside car for showing information related to navigation and speed, fuel etc. AR has large potential in enhancing the performance of driving and helping keep the eyes of the driver on the road which helpful in avoiding accidents. By analyzing advantages and disadvantages of the AR HUD, it was found that perceptual tunneling is a serious problem from safety perspective (Pullukat, Tanaka and Jiang, 2020, Wickens and Alexander, 2009). Many luxury cars of BMW, Mercedes, Panasonic and more are introducing information on windscreen of the car. If the perceptual tunneling persists for long time, it can have adverse effect of situational awareness leading the driver to not notice upcoming obstacle. This might lead in accidental situations. One of the possibilities of reduced situational awareness can be not noticing obstacle reaching close or car or suddenly appearing on or near the road. Many algorithms have been explored to highlight or cue the obstacle. This should help identify potential collision scenario and alert the driver about the same. This study explores effective way to make a car driver aware of the obstacle in low visibility driving conditions. In order to derive that effective way to show obstacle on AR HUD, expert interview was conducted to understand what should be considered while designing for AR HUD. Literature review was done to identify specific research problem and identify important saliency features of AR object to present on AR HUD. The experiment result indicated that AR objects help get attention of driver towards the pedestrians but do not directly influence reducing the response time to the obstacles. In the end this study presents a dos and don’ts when it comes to designing for AR HUDs and stated guidelines.

Preface

This master thesis is the last work of two-year Master of Science in Interaction Design program at the Design Department of Norwegian University of Science and Technology (NTNU). With this, the master's study is concluded. Although this thesis has been a 6-month long coursework during spring 2021, it actually has been a yearlong project. The Research Project Planning began in fall 2020 with which the foundation and planning of this thesis was created.

Studying in this program has been one of the most honest learning phases that I wanted to be in. Studying in Norway for two years has not only been the unique experience. With all the enthusiasm, I landed on this particular topic because of two reasons. The first reason is that I wanted to explore what is it like working with disruptive technologies like AR and VR. The second reason is that having worked as a UX Designer prior to studying masters I had designed interfaces for phone, tablets and desktops. I was very curious to see how design can be applied to products other than phones, tablets, desktops. While working on the project of Experts in Teams class in Autonomous transport specific village, I realized there is much potential to solve complex problems in automobiles with design skills and knowledge. With the freedom to choose a topic, I kept exploring design opportunities and challenges in automobiles. With more reading and guidance from my supervisors and co supervisors, I landed on this topic.

With this work, I hope to establish importance of prioritizing design centric approach to solve safety related problems. I hope to highlight the need to define standards for interface design when it comes to Augmented Reality Head Up Displays in automobiles.

Acknowledgement

Writing this thesis and conducting scientific experiment has been a long journey filled with confusion, uncertainties and happy surprises. I want to thank following people as completing this journey would not have been possible without them.

I want to thank my supervisor Ole Edward Wattne for his continuous guidance and support. He has been excellent at giving good directions. His positive approach in all the meetings, even though I was delayed in achieving planned checkpoints from the project plan has given me hope.

I want to thank Giovanni Pignoni who is my co-supervisor for influencing me to think critically while taking important decisions during this thesis. Thanks for your patience when going through NSD application. Thank you for being the go-to person and helping me understand about the eye tracker. Your support for taking driving footage is priceless.

I want to thank Frode Volden who is also my co-supervisor for showing enthusiasm for this thesis and experiment and helping with data analysis. His expertise in data analysis have helped me visualize how to process and analyze data. Figuring out SPSS would have been very difficult without your help. Thank you for giving me the GoPro for the experiment and helping with taking driving footage.

I want to thank my mother Indumati and brother Parikshit for supporting my decision to pursue master's at NTNU. I am sure my father Pandit Karande would have been happy to read this thesis. Thanks to my well-wishers who brought enthusiasm during dark winter and while I wrote this thesis. Thank you Pegasus the cat for giving me company every now and then, there was no dull moment in your company.

Thank you, Institute of Design – NTNU for giving space to all master's students. Having a place to go to study has helped me during this pandemic.

Thank you to the experts who took out their valuable time to talk with me.

Thank you to all the participants who took efforts to come to experiment room and participant.

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List of Abbreviations

AR	Augmented Reality
VR	Virtual Reality
HUD	Head Up Display
HMD	Head Mounted Display
POV	Portable Document Format
GPS	Global Positioning System
VES	Vision Enhancement System
NTNU	The Norwegian University of Science and Technology

1 Introduction

Augmented Reality (AR) is a very popular field of study and experimentation. AR systems enhance the real world by superimposing computer-generated information on top of the real-world view (Furht, 2006). Many researchers group AR under the category: Immersive technologies along with Virtual Reality (VR). (Bark et al., 2014) found that vehicle navigation systems can be improved using AR as this can reduce the ambiguity of instructions and directly point out intersections and turn locations in context to what driver sees. Studies have found that Augmented Reality has been useful for improving performance in terms of speed and accuracy of navigation (Goldiez et al., 2007) and providing a medium to enhance real-world environment with virtual information (Lochhead and Hedley, 2018).

Many times, this AR technology is associated with Head Mounted Displays but (Krevelen and Poelman, 2010) argues that AR is not restricted to particular display technologies such as a Head Mounted Display (HMD), nor is the definition limited to the sense of sight, as Augmented Reality can and potentially will apply to all senses, including hearing, touch, and smell. The type of devices that support this technology has been widened from just mobile phones or computers to tablets, holograms, smart glasses Head-Up Displays (HUD) and more. Over the past few years, HUD have gained attention to demonstrate AR. The use of Head Up Displays started in military aviation industry in planes, jet and they have been using this for a number of years but, more recently, there has been a significant interest in their use in commercial aircrafts and automobiles (Biswas and Xu, 2015). (Ward and Parkes, 1994) predicts that with betterment in the technology and proliferation of intelligent vehicle highway systems (IVHS) that help in collision avoidance, route navigation, driver status monitoring and vision enhancement systems (VES), the HUD can be used as the primary display in the car. Much research has been done to make use of AR HUDs for obstacle detection, increasing safety for elderly by cueing the elements in front (George et al., 2012), (Schall et al., 2012) and also claiming for better user experience (VRROOM, 2020) (BMWUX, 2018).
(Narzt, Pomberger and Ferscha, 2006) mentions that the visualization paradigm put forward using AR removes few constraints like seeing beyond the obstacle in front of the vehicle that gives a sense of how much traffic is further or how long is the next turn, whereas there are also studies showing that use of AR can be bad for safety. Studies that show AR can cause cognitive tunnelling with use of which the driver just keeps eyes on AR objects shown on the HUD and may lose the context of what is happening in surrounding (Pullukat, Tanaka and Jiang, 2020). Another drawback is how AR HUDs can direct the drivers' attention away from critical road elements that are not augmented by the display (Kim and Gabbard, 2019). (Hwang, Park and Kim, 2016) found that all drivers belonging to all ages experience distracted driving. A possible cause of this could be deficit in executive functions. Situational awareness is important while driving therefore altering the attention of driver that may cause perceptual tunnelling or inattentional bias towards other environmental elements is a hazard for safety of driver.
While the studies mentioned above state how usage of AR HUDs can introduce cognitive tunneling, they open up a new area of finding solutions to these problems. (Kim and Gabbard, 2019, Wolffsohn, 1998 as cited in Kim and Gabbard, 2019) (Schall et al., 2012) Show how AR objects were able to draw attention of drivers on a very specific object from outside for example pedestrians, road signs. Highlighting such objects, in this case using AR objects, is called cueing.

Then the natural question is how can we make the driver aware of the obstacle using this technology while there might or might not be effect of perceptual tunneling?

This study focuses on finding effective way to highlight an obstacle on AR HUD to the car driver in low visibility conditions, specifically nighttime driving. In addition, this study recommends considerations while designing for AR HUDs.

1.1 Research question

What is the effective way to make a car driver aware of obstacle in low visibility conditions using Augmented Reality (AR) technology?

Research hypothesis

Obstacle cuing using AR objects on AR HUD is effective way to alert a car driver about the obstacle.

Independent variable

1. AR object

Dependent variables

1. Noticeability
2. Response time

Operationalization of variables

1. AR object: Icon or graphic used to augment the obstacle on AR HUD. More specifically, the color and shape if the icon used in the experiment.
2. Noticeability: Time taken to establish gaze on the AR object after it appears for the first time in the scene in the video footage.
3. Response time: The time taken to press brake to skip the pedestrian after establishing gaze on the pedestrian. (Park, Kim and Kwon, 2017) defines the driver's response time as "The amount of time that elapsed between the presentation of an unexpected or dangerous event and the application of the brake."

Along with the main research questions there are many underline questions that come along the way that are important to answer too, such as,

1. How can we reduce perceptual tunnelling?
2. Does saliency of cued pedestrian increase or decrease by changing color, line thickness, shape of the icon used to cue?

1.2 How is this topic relevant to Interaction Design?

> "Augmented-reality interfaces are an example of noncommand user interfaces in which tasks are accomplished using contextual information collected by the computer system, and not through commands explicitly provided by the user." – (Nielson Normal Group, 2016)

(Nielson Norman Group, 2016) states one of the benefits of AR as decrease in the interaction cost. Decrease in interaction implies more reliance on effective communication of the information. Study of AR Interfaces and specifically the HUD in car navigation is significant and important as it is one the most important channel through which the human and the machine communicate. The HUD differs from other type if user interfaces as there is no keyboard, mouse, touch to interact with it. Instead, the AR HUD is an important interface that's established communication with the driver. The communicated information can influence what action the driver needs to take. Contrastingly, actions of the driver reflect parameters like speed and distance till the next turn or roundabout. The design and visualization on AR HUD are very critical due to the fact that driving a car is very complex task and this is related to safety critical system. Therefore, even a minor mistake in design of functioning can lead to high cost causing fatal accidents. In this 21st century, humans are fairly good at interpreting information on computer, mobile and display interfaces. There exist guidelines to structure information on computer and mobile interfaces based on which humans have learned where to expect what information. For example, when one is using Apple laptop, to know what time and date is today, one can expect to find it on the top right corner of the screen. When it comes to windows PCs, one can expect to find it on bottom right corner mostly. But when it comes to finding information related to obstacle on AR HUD, no guidelines have been formally established. Therefore, effective communication through AR HUD is very important. This requires good information design for given task in given context of the safety critical system. Therefore, this topic is important in Interaction Design.

This thesis follows a User Centered Design approach. The goal is not to design a new AR interface completely but to find effective way to visualization obstacle cues so that the driver can react to avoid accident situation. Section 2 details out each step and the method used to address the research problem, evaluate the solution and draw the results.

1.3 Assumptions

This study assumes pedestrians as obstacle whereas obstacle could be road sign, animals, other cars or other objects coming on the road. In addition, this study assumes that the perceptual tunneling occurs with the persistent Augmented information shown on AR HUD, which is speed and speed limit information used in the experiment. See section 3.2.

1.4 Planned contributions

This thesis intends to highlight importance of design aspect while solving problems related with AR HUD features.

- This study confirms the findings done by other studies about AR cuing being useful at drawing quick attention of the driver.
- This study opens paths to do further research and conduct experiment. Section 6.1 Future work frames possible questions to follow for future studies.
- It is hoped that this study influences automobile companies to pay attention to possible safety issues that AR HUD technology is imposing and hence attempt to form common guidelines that work for all cars as a common safety critical system.
- With this thesis, the researcher also hopes that existing design processes, user centered design can be followed to address and solve problems related with automobile industry, more specifically information design on AR HUDs.

1.5 Thesis outline

The thesis is divided in 6 chapters as follows

Chapter 1: Introduction
Introduces the technology and domain in focus. Funnels down to problem area and then research question. Furthermore, specifies the dependent and independent variables along with their operationalization. Finally states the assumptions and planned contributions.

Chapter 2: Background
Builds a thorough context of the technology in focus. Covers a part of history of AR, presents different types, recent developments and various issues that are faces currently specific to usage of AR in HUDs. Finally details out tunnel vision aspect. Introduces the technology and domain in focus. Funnels down to problem area and then research question. Highlight usefulness of eye tracker for this study.

Chapter 3: Methods
Shows overall process followed to define research problem and conduct rest of the study. Explains purpose and details about each method followed during each phase of design process. Details out methods used to collect data as well as analyze and process the collected data. Covers ethical and legal consideration in the study.

Chapter 4: Result and Analysis
Is divided into 3 parts. Described what type of data was gathered form qualitative and quantitative research methods. Shows how gathered data was processed and analyzed.

Chapter 5: Discussion
Is divided into 3 parts. First part shows outcomes seen in results and shows observations made. Discusses in detail the result and why certain results might have been there. States what can be improved. Second part critiques the validity and reliability of the study. Third part states the overall limitation of the study.

Chapter 6: Conclusion
States the answers to the research question frames at the beginning of the study. States what could have been improved. Frames a few questions that can be taken for future studies.

2 Background

2.1 Immersive technology: AR and VR

Augmented Reality and Virtual reality are mostly mentioned together whenever one of the technologies is mentioned. Both of these technologies are part of immersive technologies that are increasingly pervasive in our daily lives (Suh and Prophet, 2018) (Lelyveld, 2015). The first mention of Augmented Reality was made by Philip K Dick somewhere between 1928 to 1982 in a science fiction book written by him (Peddie, 2017). Not just the Augmented Reality but many technological advances were made visual even before that technology came in existence through various science fiction movies, comics and books.

Earlier on the Augmented Reality was used in military and for industrial and scientific purposes with many limitations on the financial budget (Peddie, 2017). Although the use of AR through HUDs Augmented Reality made its first presence in Gartner's Hype Cycle for Emerging Technologies (Gartner, 2016) since 2016 and it has been there till this date. Augmented Reality gained popularity when it started reaching out in consumer markets in forms of apps and games. Pokémon Go is one of the most popular game that most people know when it comes to Augmented Reality Games. Supermarkets like IKEA uses the technology to create experience of visualizing the products in customer's home. Snapchat has and is coming up with many new face filters where users can augment their face with digital object for beautification or other purposes.

Before we go into details about one technology in later chapters, it is important to understand what Immersive Technology is and the difference between Virtual Reality and Augmented Reality is. (Lee, Chung, et al., 2013 as cited in Suh and Prophet, 2018) defines the Immersive Technology as "the technology that blurs the lines between the physical and virtual worlds". Immersive technology such as head-mounted displays, computer-generated kinesthetic and tactile feedback tends to increase the users' subjective sense of presence (Soliman, Peetz and Davydenko, 2017).

The Virtual reality is defined as -

> "The use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence." (Bryson, 2013).

This means having existence of something without it being really present for real (Bryson, 2013). After Bryson the definition of Virtual Reality had undergone many changes. (Lelyveld, 2015) states the Virtual Reality being the art of stimulating a physical presence for the audience in places both real and imaginary. But Augmented Reality differs from Virtual Reality. (Lelyveld, 2015) differentiates these two technologies by identifying them to be on very opposite end on a spectrum of experiences. A simple way to differ these two technologies by thinking about the relationship between where our body is located and how much of what you experience is artificial. According to his terminology, when there is a little window of additional (digital or augmented) information in your field of view, then that experience is Augmented Reality Experience, but when you are only able see the projected objects regardless of if they are live or computer generated then that experience is Virtual Reality Experience. Whereas (Peddie, 2017) differentiates these two technologies stating that Virtual Reality takes you totally out of actual reality and replaces the real world with a simulated one, whereas Augmented Reality enhances your actual reality.

2.2 Definition of Augmented Reality

The Cambridge Dictionary defines the word 'Augment' as "to increase the size or value of something by adding something to it". The term Augmented Reality therefore implies that the reality getting augmented by something.

(Furht, 2006) defines AR as "Augmented Reality is a system that enhances the real world by superimposing computer-generated information on top of it". The digital content for example text, images, animation is superimposed on the real-world view of the user (Peddie, 2017).

(Peddie, 2017) predicts that Augmented Reality is going to disrupt various fields and use of Head-Up Displays (HUD) in automobiles and various transport vehicles will become so common that it's absence will make us feel uncomfortable.

2.3 Types of Augmented Reality

(Peddie, 2017) categorizes AR into two types based on their wearable and non-wearable property. Further these are categorized based on area of usage and context i.e., indoor or outdoor. In addition, Ron Pandzensky has detailed out the taxonomy based on type, design, form factor, class, sensing and control as shown in Figure 2.1. The type of hardware in consideration for this study is similar to Vehicular Windscreen (Continental AR-HUD) under Projected category.

While talking about the social issues and user interactions of AR in real world, (Narzt, Pomberger and Ferscha, 2006) states that in order to make the system react to person's gestures, either the person should be equipped with additional sensor on their body, or the person should be in an environment that recognizes the gesture or other data input. This way a car is biggest accessible environment since it has tracking equipment (GPS), and the windshield that can be the display showing AR objects on real world view. Therefore, windshield as HUD suits best to show augmented objects in context to driving.

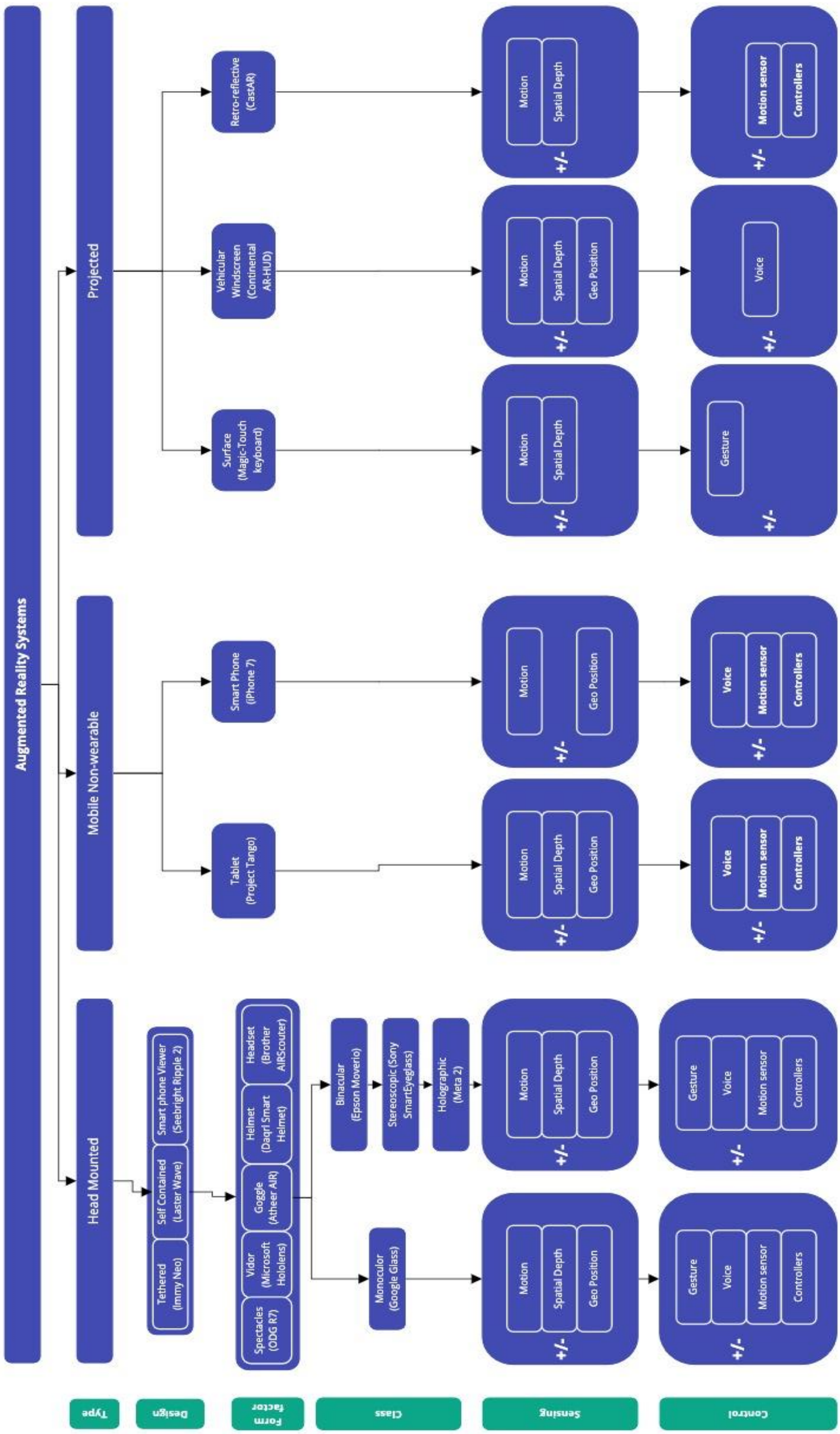

Figure 2.1 Taxonomy of AR hardware by Ron Padzensky (Peddie, 2017)

2.4 Head Up Displays

Focus of this thesis is on the HUDs as these displays are used in car for superimposing the AR objects. (Peddie, 2017) mentions two kinds of HUDs, the first one is low-cost retro-fit HUD that sits on the dashboard of a vehicle and projects information such as speed, engine, water temperature, battery voltage, instantaneous fuel consumption, average fuel consumption, mileage measurement, shift reminder and other warning conditions as shown in figure 2.2. All this is projected on inside surface of the windshield. The second kind uses a smartphone application that displays speed and navigation information. The use of HUD is not limited to just cars, but it can be used in buses, trucks and even ships. (Biswas and Xu, 2015) Explains two classes of HUD. The first one with a projection device forming a small field of view (FOV) and the second one where an optical film coated with nanoparticles is used on the windshield that gets illuminated by a light engine with invisible UV spectrum to form a visible image. The second kind produces a real image and often creates a larger FOV. This study assumes that the HUD in focus is similar to this second kind as mentioned by (Biswas and Xu, 2015)

Figure 2.2 Hudway Glass offering information from a smartphone (Peddie, 2017)

HUDs allow the driver to simultaneously visualize both the information on the HUD and the background due to the fact that the HUD is transparent (Liu et al., 2019). On account of the fact that HUDs allow simultaneous visualization as the distance and the time of the eye movement are reduced. As a result of which the reaction time of the driver is improved as compared to when the information is presented on a multi-information display of the car.

(Ward and Parkes, 1994) classifies the usage of the HUD application into two types –

1. A display to show coded information continuously (e.g., speedometer) or intermittently (e.g., route navigation and collision warning symbols
2. As a display for vehicle enhancement system (VES) for use in conditions of restricted visibility (e.g., nighttime, fog)

This study focuses on usage of AR HUD during low visibility conditions such as nighttime driving.

2.5 Recent developments and safety concerns

While AR is enabling us to extend our vision when driving (Narzt, Pomberger and Ferscha, 2006) there are many disadvantages to this. By bringing the information in the FOV of driver, the attention gets divided. There are good and bad effects of this.

On the good side, many studies report that the navigation performance and visibility can be improved by showing intersections, turn locations in context to what driver sees as it would reduce the ambiguity of the instructions (Bark et al., 2014; George et al., 2012; Gregoriades and Sutcliffe, 2018; Biswas and Xu, 2015). The technology is not just enhancing the visualization for humans but for autonomous vehicles too (Qiu et al., 2019). The cued objects using AR helped elderly people by improving response rate and response time in contrast with un-cued conditions (Schall et al., 2012).

Whereas on the bad side there is bigger cost to pay if these augmented objects cause delay in the decision making of driver when it comes to reacting fast in accidental situation. When the driver's is not able to quickly interpret meaning of hazard warning while driving then this is a problem of divided attention. This divided attention makes the safety of the driver suffer (Wickens, 2002 as cited in Gregoriades and Sutcliffe, 2018). In order to ensure the safety of the driver, the system should not take driver's attention away by making them compromise on the driving task. On the other hand, information overload causes poor situational awareness, and this can reduce the information scanning capability of the driver, eventually resulting in driver ignoring other important stimuli (Endsley and Jones 2012 as cited in Gregoriades and Sutcliffe, 2018). This compromise on situational awareness worsens even more for novice drivers as they have less than optimal visual search strategies than the experienced drivers (Konstantopoulos and Crundall 2008 as cited in Gregoriades and Sutcliffe, 2018). Therefore, it is important to find out how can we make the information easily scannable, easy to interpret, that does not result in division of attention but instead enhances the situational awareness.

2.5.1 Change of context from aviation industry to automobile industry

(Pullukat, Tanaka and Jiang, 2020) The use of HUD has become popular in automobiles after getting the inspiration from aviation, military industry but the context changes largely from a pilot flying a plane and a driver driving a car. Pilots are trained to make sense of the information shown on HUDs whereas training drivers is not a part of the driving class or examination. This opens doors for individuals to interpret the information in a way that might not be common among many. The amount of information shown on HUD of a plane is not comprehendible by a car driver due to the fact that it is too much information. The external environment of a plane is more controlled, there are less and less frequent surrounding objects like other planes, mountains. Whereas in the external environment of a car, the number of potential obstacles is higher, there are more and more frequent obstacles and the reaction time to those while driving has to be very low (Pullukat, Tanaka and Jiang, 2020). Therefore, the amount of information, clarity of the information should be well thought of when introducing it on HUDs of automobiles because that can have direct impact on the reaction time. Hence, to optimize the use of HUDs, only the most useful and unambiguous visual cues should be shown to the car driver (Fadden, Ververs, and Wickens, 1998 as cited in Gregoriades and Sutcliffe, 2018).

(Dellis 1988; Sojourner and Antin 1990; Swift and Freeman 1986; Weintraub and Ensing 1992; Yamaguchi 1988 as cited in Ward and Parkes, 1994) The HUDs in automotive applications are used to display vehicle speed, turn and hazard signals, headlight beam indication, and alerting messages to direct the driver's attention to relevant panel-mounted displays. Whereas those used in aviation applications tend to display information at a closer optical distance because much of what the driver needs to see is closer than optical infinity.

(Ward and Parkes, 1994) derives from the literature review that it is not practical nor advisable to transfer the HUD directly to the automobile from parallel aviation applications. It is further recommended that the use of HUD needs to be fundamentally thought through so that performance and safety benefits can actually be realized. (Ward and Parkes, 1994) The HUD should not be considered simply as an alternative display opportunity to show information on. This need of reconsideration necessitates the reconsideration of the fundamental characteristics of the HUD as a display and the information to be shown on it.

(Ward and Parkes, 1994) states that there are significant differences between the driving task associated with aviation and that of driving on the road although both require high level of visual attentions to the outside world. One of these differences is that the pilot relies predominantly on flight instruments for information, whereas the driver needs to pay continuous eye contact with the road to maintain proper lane position. The use of peripheral vision may be much more important in driving for directing selective attention to the various elements present in the driving environment that must be attended to. The pilot's forward view contains few obstacles whilst in flight (i.e., potential hazards to avoid).

2.5.2 Level of automation

(SAE International, 2018) also called as Society of Automation Engineers provide a taxonomy that shows there are total 6 levels of automation when it comes to motor vehicles. See Figure 4-3. These levels start from 'level 0' and end at 'level 5'. Level 1 refers to no automation and level 5 refers to full driving automation. The driving automation system can consist multiple features, each feature can belong to different level of automation. The level of the automation at certain moment is determined by the level of automation of feature that are engaged at that moment.

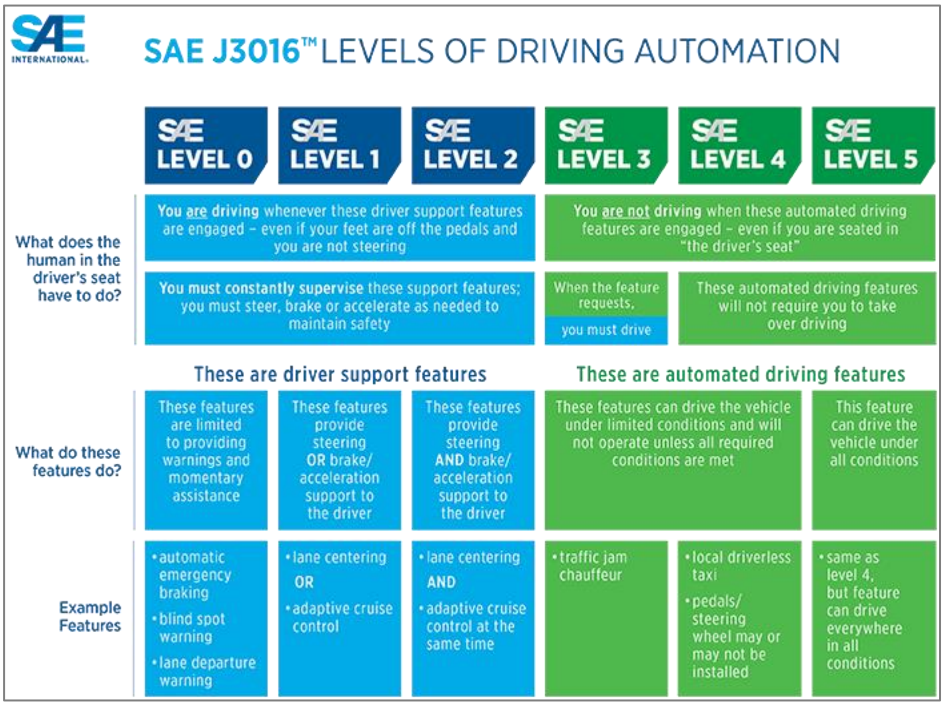

Figure 2.3 Levels of driving automation (SAE International, 2018)

2.5.3 Effect of impaired vision or sight on driving

(Ortiz-Peregrina et al., 2020) conducted a study to examine the association between age related vision changes and simulated driving performance. The results of the study demonstrated that older drivers drive less efficiently. The study further concluded that the older drivers were found to have diminished visual acuity, poorer contrast sensitivity and were influenced more by the glare. Aging introduces changes in the ocular structures that includes a marked loss of lens transparency, which causes a significant increase in light scattering by the eye's optical media, therefore aged people have more contrast sensitivity (Martínez-Roda et al., 2016). (Gruber et al., 2013) found the correlation between increased glare sensitivity and impaired night driving. Since aging is one of the factors increasing the glare sensitivity, the task of night driving stands challenging for aged ones. (Molina et al., 2021) the literature informs that drivers who are visually impaired change their driving behavior in order to response to a loss of visual function over time (reduced driving miles, lowering driving speed, increasing safety margins). (Molina et al., 2021) conducted a study and found out that drivers, when facing deteriorated binocular vision, experienced high task complexity while their subjective perception of driving safety was significantly lower in monocular viewing conditions. Higher task complexity can potentially induce higher workload on the driver. This evidence addresses the need of including the userbase having impaired vision either due to age or impaired vision due to other factors. To make the design of HUD interface universal, making the designs usable for all user groups is very important. (Ward and Parkes, 1994) recognizes the primary purpose of the HUD is to reduce time needed to obtain display information with attention maintained on important outside world. Furthermore, it associates this as helpful for older people since aging can cause degradation in accommodative mechanism.

2.5.4 Information overload and effect of stress on peripheral vision

The design of how the information is shown on HUD should be intuitive to the driver. The next natural question is how much information too much and how much information is good to comprehend without leading to information overload. (Park and Im, 2020) conducted a study where it found that in semi-autonomous car, there should be maximum 6 symbols for effective understanding. But considering a non-autonomous car there is scope to find out how many symbols are effectively understood.

(Ward and Parkes, 1994) found a few laboratory studies which demonstrated that performance of peripheral visual detection might get significantly impaired under physical or emotional stress, or under increased levels of information processing load. The cause of such degradation of peripheral performance has been interpreted as a narrowing or focusing of attention. In a review of a series of experiments on information processing, (Sanders, 1970 as cited in Ward and Parkes, 1994) discusses the concept of the "functional" or "effective" field of view that shrinks or expands depending on the perceptual load of the task.

This effect has been called "tunnel vision" (Mackworth 1965; Williams 1985a, 1985b as cited in Ward and Parkes, 1994), "cognitive tunnelling" (Dirkin 1983 as cited in Ward and Parkes, 1994), or "perceptual narrowing" (Lee and Triggs, 1976 as cited in Ward and Parkes, 1994).

There is a trade-off between the benefits of an enhanced central area within the field of view (e.g., increased target detection) and a reduction in attention to peripheral areas (Ward and Parkes, 1994). This suggest that there should be balance between how much information to show in the field of view versus how to make sure that the attention to peripheral areas still remains sufficient for situational awareness. This affects the speed and distance judgements of mis accommodation induced by the HUD may have a serious impact on safe traffic negotiation and collision avoidance.

Effective driver behavior in traffic situations requires rapid response to cues that are embedded or camouflaged in complex stimulus fields (Goodenough 1976 as cited in Ward and Parkes, 1994). In relation to this, (Shinar et al., 1978 as cited in Ward and Parkes, 1994) have observed that field-dependent (those who rely more on external referents or environmental cues) individuals have less effective visual search patterns and require more time to process visual information available within the driving environment. (Ward and Parkes, 1994) draws from the literature that that field-dependent drivers are involved in more accidents than are field-independent drivers. Therefore, states that this situation can be worsened by the additional need to extract critical information from virtual images superimposed in space upon an already complex and taxing environment.

2.5.5 Color and saliency of AR information

(Ward and Parkes, 1994) It was reported in a literature that the color-coded objects used on HUD were more easily and quickly distinguishable than those objects that differed by shape or size. Contrastingly the author recommends use of monochromatic colors on HUDs. This although color coding has been shown to be advantageous over shape coding in conventional displays, the advantages have not been proven for HUDs specifically.

(Ward and Parkes, 1994) relates the issues in HUD applications to human factor issues as these relate to the basic human information processing characteristics. These issues are-

1. Illumination and reflection
2. HUD size and placement
3. Binocular disparity and diplopia – double images resulting
4. Information clutter
5. Background scene complexity
6. Characteristics of use population
7. System fidelity and robustness

Author moreover discusses a few areas that highlight the issues and design specifications of the HUDs in automobile industry and specifically for HUD optics it has been recommended viz. HUD optics, HUD specifications, manual control, CRT luminance requirement, combiner transmittance, binocular disparity, optical distance of display and HUD eye box. Among these factors, when focusing on the HUD optics, the author highly recommends usage of monochromatic CRTs. The basis of this recommendation is that, not only does the narrow band of a monochrome display result in greater symbol reflectivity and scene transmissivity at the combiner, but color presentation has a number of technical and functional disadvantages.

(Liu et al., 2019) After conducting an experiment realized that the saliency of blue color on black background was lower than that of the others.

Red holds an important place when it comes to human-machine interfaces (Liu et al., 2019) recommends using red color in HUDs with care as it's saliency often gets reduced compared to other colors. The reason being there are many warm light sources such as beak lights, sunset, yellow streetlights that overlap in the background of the information shown on the HUDs

(Liu et al., 2019) observed that the saliency of the projected information on the HUD was significantly lower than the saliency of the background. (Liu et al., 2019) there is a bigger disadvantage or limitation associated with HUDs and that is their transparency. This causes difficulty in visualizing projected information such as texts, icons and graphs when it overlaps with a background of the same color. Most HUDs used in the airplanes are monochromatic e.g., green or orange (Wood and Howells 2000 as cited in Liu et al., 2019), on account of the fact that there is typically limited range of colors in the sky background (white for clouds, blue for the sky, black for the night sky). In case of vehicles on the road, there are many objects of various color, shape, sizes, speed for example trees, other vehicles, pedestrians, traffic markers. Such environment is much more complex than the sky scene therefore the overlap of such background with the information might affect the ability of the driver to recognize the visual element of the HUD. This may result in potentially dangerous situation, especially in an emergent case such as rush-out of a pedestrian in front of the vehicle.

(Liu et al., 2019) observed that the saliency of the projected information on the HUD was higher than the saliency of the pedestrian component. This situation is likely to increase the risk of an accident when the driver is distracted by the information on the HUD.

(Liu et al., 2019) In presence of the glare, the saliency of the projected information on the HUD reduces. Glare refers to stray light not only from the sun, but also from the brake lights of proceedings vehicles and the headlights of oncoming vehicles. It was further confirmed that the saliency of the information on the HUD is reduced by the light conditions (glare from the sun, the brake light of a vehicle, headlights in the opposite lane, etc.)

2.5.6 Tunnel vision and cognitive capture

Cognitive tunnelling (Pullukat, Tanaka and Jiang, 2020) and inattentional blindness due to frequently changing information on HUD (Wolffsohn, 1998 as cited in Kim and Gabbard, 2019) raises serious concern related to safety of the driver while using HUD. There are solutions proposed to detect the obstacle of potential threat that can lead to collision. Many studies use cueing technique to highlight the object from the environment which are either road signs or those with which the car might collide (Kim and Gabbard, 2019; Park and Kim, 2013; Schall et al., 2012; Merenda et al., 2018; George et al., 2012; Eyraud, Zibetti and Baccino, 2015; Park et al., 2015). On the contrary there are studies that have tested their collision detection algorithms using a simulator that created environment as same as car using set of monitor screens to depict windshield and addressed that cueing just attracted the gaze of the driver and did not necessarily made the driver to immediately understand the meaning of the cued object.

2.5.6.1 Cognitive capture

(Ward and Parkes, 1994) Humans can only process limited amount of information at given time therefore we would naturally require more time to process the information provided by assisting systems in car. In addition, the increased information can result in diversion of usual attentional processes. Hence, just as it can be beneficial to show important information, it also has the potential of circumventing driver's attention away from the important conventional information sources especially those in the periphery of the driving scene.

HUDs can help facilitate fast switching between displayed information and the outside world. There are both pros and cons to this as mentioned by (Ward and Parkes, 1994). On the positive side, the switching is fast. On the flip side, this process disrupts the most common process of switching the attention that involve three stages viz., (i) looking up, (ii)changing the accommodation, and (iii) changing convergence. These act as a strong cue to indicate that the switch of the attention is taking place.

Although HUDs were designed to facilitate rapid switching of attention between displayed information and the outside world, the proximity of information from both sources may actually disrupt that process. For example, when switching from conventional head-down (i.e., panel-mounted) displays to view the outside scene, there are three strong cues that indicate that a switch of attention is taking place:

(i) looking up,
(ii) changing accommodation, and
(iii) changing convergence.

These may be powerful reminders to switch attention (Weintraub and Ensing 1992). With a HUD there may be no such cues. Furthermore, humans may not be accustomed to dividing attention between information that is superimposed in visual space; and the display of information in the visual field may draw attention away from the outside scene without the vehicle operator being aware (Wierwille and Peacock 1989; Weintraub 1987). This attention-grabbing effect of HUD images has been termed "cognitive capture" in the literature.

An experiment at NASA showed the evidence of such cognitive capture where the subjects took more time to detect obstacle when using HUD than when using conventional instrument (Fischer, Haines, and Price 1980 as cited in Ward and Parkes, 1994). In addition, they suggest that the effect of cognitive capture on performance may be restricted to low-probability or unexpected events (the type of event that contributes to accidents) in both aviation and driving. (Ward and Parkes, 1994) it was not clear what effect the HUD and its presented information will have upon the cognitive and behavioral functioning of motorists. For example, provocative contact analogue images produced by VESs may appreciate cognitive tunnelling.

2.6 Use of eye tracker for testing hypothesis

> "Eye tracking is the process of measuring either point of gaze or the motion of an eye relative to the head" – (Peddie, 2017).

(Peddie, 2017) Eye trackers have the ability to detect where the eye is looking very rapidly hence are better to enable designers and developers to deliver content to the viewer more efficiently. Among all the studies refereed in this report that had to do with studying cueing or highlighting objects on road through HUD, almost all (Eyraud, Zibetti and Baccino, 2015), (Kim and Gabbard, 2019), (George et al., 2012), (Merenda et al., 2018) have used fixed sensor eye tracker in contrast with the on eye/ wearable eye tracker used by (Bark et al., 2014). The advantage of fixed sensor eye tracker is when user does not have to move head but just the eyes while performing the task. In methodology chapter the experimental setup is described where the simulation room is created, and the participant will be asked to sit in a fixed position that would not encourage much of a head movement. Following the path of most experiment, eye tracker will be used to make relevant conclusion. The most common parameter that is obtained using eye tracker in these studies is gaze and fixation. Using gaze, gaze behaviors can be assessed that can reveal the behavioral aspect of result and can lead to understanding of something that is not merely visible to the moderator that can be noted in diary. Due to the fact that the eye movements are very fast and are difficult to track by other human eye and derive conclusions. The other parameter which is the fixation or fixation pattern reveal where the participant was looking mostly. Tracking this can lead us in understanding whether area with most fixation was of any importance or was explicitly highlighted or whether we were able to draw attention of the participant on planned AOI. For this thesis, the variables related with gaze for example average gaze time, gaze pattern etc. and variables related to fixation should be considered for analysis.

This thesis aims to compare the effect of variation of saliency of AR information on perceptual tunnelling.

Next chapter describes the methods that will be used in this thesis.

3 Methods

This chapter explains the methods involved to perform literature research to frame the research problem and build deep understanding about the topic and for gathering the quantitative and qualitative data.

The initial phase to reach the research question and hypothesis takes an inductive approach. The overall methodology is divided into 3 main parts viz. research, prototyping and testing. See Figure 3.1. The methodology follows user centered design principles (Baxter, K., et al., 2015).

Following topics elaborate each phase and method in detail.

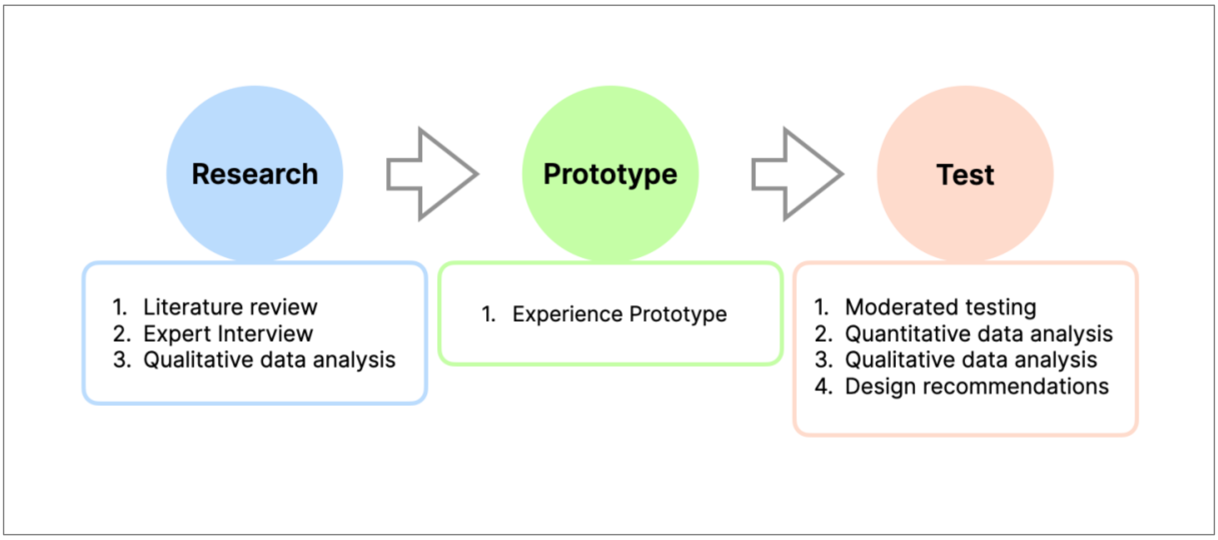

Figure 3.2 Process diagram

3.1 Research

3.1.1 Ethical considerations

The purpose of this method is to ensure that research carried in this study follows ethical and legal guidelines. In Norway, there are strict rules about gathering data from public and using the data for research. When it comes to conducting research experiment that involves inviting participants, there are following ethical and legal considerations that the researcher must take care of (Pignoni G., 2020)

1. Protection from harm
2. Voluntary and informed participation
3. Right to withdraw
4. Right to privacy
5. Intellectual honesty

In order to have permission to collect personal information of participants, NTNU follows NSD (Norwegian center for research data) instructions. Guidelines provided by NSD adhere to ethical and legal considerations applicable in Norway. An application was submitted to nsd.no explaining the purpose of data gathering, what kind of data would be gathered, Interview guide with question that would be asked, and sample involved in data gathering process.

3.1.1.1 Protection from harm

Neither of the methods or stimulus presented in the observation study involved task or activity that would induce unusual stress, embarrassment, loss of self-esteem or psychological harm. Therefore, this thesis caused no harm to the participants.

3.1.1.2 Volunatry and informed participation

This involves informing participants about experiment, what type of data will be gathered in the experiment, their right to privacy, right to withdraw. A consent form was given to the participants. In addition, this form included information about the project and the rights of the participants. The consent form used are attached in appendices. See appendix 1 and appendix 3.

3.1.1.3 Right to withdraw

All the participants taking part in the study do this voluntarily therefore have right to withdraw their participation anytime they wish. If the participant feels uncomfortable or does not want to be a part of study anymore even after the study has started, the participant was able to quit and leave the study environment. The procedure to withdraw and this possibility was informed to the participant in the information letter. No penalty was involved if the participant decided to leave the study.

3.1.1.4 Right to privacy

None of the personal information written or recorded was revealed publicly revealing the identity of the participant.

3.1.1.5 Intellectual honesty

This thesis is a part of master's program at NTNU. The application for publishing will be done through NTNU. Therefore, this is the property of researcher and NTNU. No external party can claim ownership of results coming out of this thesis. The ideas, solutions proposed in this thesis are not allowed to be copied without giving credit.

3.1.1.6 Contact with vulnerable user group

Explicitly recruiting vulnerable people is not a part of this thesis and no vulnerable individual was asked to participate in this study.

3.1.2 Literature review

The purpose of this is to get well acquainted with the research done so far in Augmented Reality in relation with navigation in automobiles. The referred literature should be at least 5 years latest as the technology is changing allot very fast and the intention of this thesis to contribute in a way that stays relevant in future as well.

The first phase of the literature review was exploratory where goal was to be aware of the Augmented Reality and Wayfinding as a field of study. To build a strong background about wayfinding and navigation the topic for specialization in Interaction design was defined as "Traditional and hybrid-wayfinding and Navigation with AR". This phase would primarily end when the report is submitted at the end of fall semester 2020. But any new addition to the wayfinding and Navigation field will be noted throughout the thesis until the experimental setup for testing the research hypothesis is done.

The second phase of the literature review focuses on use of AR HUDs in car and various studies done in this area. For this, following terms were searched on NTNU's oria.no search engine.

1. Augmented Reality
2. Immersive technology
3. Virtual Reality
4. Augmented reality in automobiles
5. Augmented Reality Head Up Displays
6. Obstacle cuing
7. Perception tunneling AND Augmented Reality

Oria is the main search engine that was referred which connected to databases: Springer, IEEE, ACM, ScienceDirect and some more. Google scholar, The Interaction Design Foundation and Nielson Norman group, design kit org were used to refer to design methods and also for studies in AR specifically associated with design. The literature review will continue further to know more about collision detection and cuing with AR HUD in cars.

3.1.3 Expert interview

The purpose of this method is to get insights from the experts in the field. (Audenhove L.,2007) mentions that an expert interview is advantageous in exploratory research since there are many advantages to this for example, high insights into specific knowledge and fast access to unknown field. This method suits this thesis as the insights from the interview can influence the design in the prototype.

Due to Its advantages like high insights into specific knowledge and fast access to unknown fields, the expert interview as a research method was chosen. The interview followed semi structured format where the questions were listed in interview guide and did not follow a strict sequence.

3.1.3.1 Recruiting process

A list of experts was made referring to the authors of the research papers read during literature review. Two experts from the list were selected and contacted for the expert interview who did not respond to the invitation. In addition to emailing the experts personally, an invitation text was posted on social media (Facebook and LinkedIn) as well as with personal and professional contacts to reach out to relevant experts. 3 people responded to the message and two of those people participated in the expert interview.

3.1.3.2 Recruited experts

Two experts were interviewed both having more than 2 years of experience working with Augmented Reality technology. One of the experts has specially worked in automobile industry. Second expert had not worked in automobile industry, however, is working with design of interfaces in Ship bridges for maritime industry.

3.1.3.3 Procedure

The experts were sent the information letter along with the consent form in advance when an online video call invitation was sent. See appendix 1 for the information letter and consent form. The experts were asked to sign the consent form if they agreed to participate. After receiving consent, the interview was held for around 45-50 minutes. The audio of the conversation was recorded using Dictaphone app.

A semi-structured interview was conducted with 2 experts. The questions were designed to get insights about advantages, disadvantages, limitations, scope of Augmented Reality technology used in automobiles. See appendix 2 for the interview guide. The audio recording of the interview was transcribed to find patterns and themes. See figure 4.2. The findings were used while creating the prototype of the experiment which is explained in next topic.

3.2 Experience prototyping

The purpose of this method is to create prototype close to the real driving experience. In order to test the effect of perceptual tunnelling involved when using the car windshield as the HUD, it is important to test it in a scenario that involves driving setup or infrastructure. Many studies have used simulation for testing the hypothesis when it comes to driving task (Cite all the papers here that have used simulators for testing). In order for the results to be close to real environment, it is beneficial if the simulation prototype gives close to real experience of driving vehicle. Usage of video clips capturing actual driving scene has proven to be useful in many experiments conducted using a simulator (Hwang, Park and Kim, 2016; Liu et al., 2019; Bark et al., 2014; Eyraud, Zibetti and Baccino, 2015; Park et al., 2015). Therefore, experience prototyping (Tomitsch et al., 2018) as a prototyping method was used. Experience prototyping is advantageous for safer method of testing driving related tasks rather than testing in actual driving conditions because the consequences of new design under testing are unknown. The simulator-based testing makes it quicker to test the solutions rather than building the real solution which can take more time

3.2.1 Prototype building

The prototype was built in a dark room that consisted of a self-made simulator. Four video clips were edited from a long footage of nighttime driving around the Gjøvik town in Norway. These clips were played on the monitor screen of the simulator for the participants. The setup was equipped with cameras and eye tracker to capture where the participant is looking and how do they react to scenes shown in the videos. Following subsections explain details about the video footage and the experimental setup.

3.2.1.1 Determinants of AR object and it's saliency

(Liu et al., 2019) has studied the effect of saliency of the AR objects in HUD on how well it can be recognized by the users under certain circumstances. As per the table shown by them, they tried different colors like white, red, green, blue on dark background from a nighttime driving scene. It was observed that red color's saliency got reduced due to the brightness of streetlights and break lights of the vehicle in the front. Therefore, they recommend avoiding it. It was observed that saliency of blue color was not reduced much. Moreover, the outcome of the expert interview informed that blue color can be used to grab attention in dark conditions and that looking at blue color does not tire the eyes compared to other colors. Based on these two reasons, it was decided that blue colored AR object would be used in the experiment. In order to test the influence of different color on how effectively it can grab attention of the driver, two variations of the video were made. The pedestrian icon used in the video was in white and blue color.

Figure 3.3 Icon augmented as pedestrian

3.2.1.2 Determinants of driving task

Humans have limited vision in the dark and therefore the need for safety increases during nighttime. Since the hypothesis to be tested is specific to nighttime driving, the nighttime driving footage was captured. A video footage of nighttime driving in Gjøvik town was captured using GoPro camera situated with help of tripod stand on passenger seat of a car. Three situations of a pedestrian coming almost on the road in front of the car were created and captured in camera. The footage involved driving on city roads where there is good lighting conditions as well as driving outside city driving where it was very much dark around the road. This footage was then edited using Adobe After effects to manually merge AR icons on windshield of the car. It was then exported to mp4 video files using Adobe Media Encoder. 4 chunks of videos were made that were shown to each participant. Two clips of training that involved city driving and outside driving. This video was played on the monitor screen.

Clip no.	Type	Driving environment	Duration (mm:ss)	Overall duration of driving footage for single participant (mm:ss)
1	Training video 1	Inside city	03:03	11:01
2	Training video 2	Outside city	05:15	
3	Task1 video	Inside city	01:32	
4	Task2 video: white icon	Outside city	01:11	
	Task2 video: blue icon			

Table 3.1 Driving clips and duration

Independent measures

1. Color of the icon: white and blue

Dependent measures

1. Noticeability of icon: Time taken to establish first gaze at the AR object after it appeared on the screen
2. Response time: Time taken to press the brakes after seeing the AR object or the pedestrian from the scene in the video

3.2.1.3 Experimental setup

The setup involved svive PYX 34C601 monitor that was 34 inch in diameter. The screen resolution was 3440 pixels by 1440 pixels. This screen depicted the windscreen of a car.

Logitech G920 Driving Force Steering Wheel and Pedal was used. The steering wheel was fixated on the table where the monitor screen was places. The steering wheel was placed slightly to the left side of the table instead of exactly center of the table. This is to give a real feel of sitting in the car because the driver seat is located on the left side of the car and not in the center when it is the right-side driving rule. The chair used in this setup was without any wheels. This is to prevent the backward movement of chair if brake pedal is pressed which would result in incorrect measurement of eye movement as compared to calibrated positions. The brakes pedal was placed below the table aligned to the steering wheel so when a participant sits on a chair in front of the steering wheel, the brakes are reachable by the foot of the participant. Using blue colored tape the accelerator and brake pedal was marked with letter 'A' and 'B' respectively to help prevent the confusion while pressing brakes or accelerating.

A GoPro3 camera was fixed on the tripod stand which was placed near the table. This camera was used to capture the view of brake pedal. This footage would help find when the participant pressed the brakes. Based on this timestamp the reaction time was calculated. The GoPro camera failed to record videos due to space issues therefore a personal phone camera of OnePlus 6 was used. Figure 3.4 shows the experimental setup with lights on in the room. In testing condition, the room is made dark to resemble with nighttime driving.

Figure 3.4 Experimental setup

Pupil core of Pupil Labs was used to track the gaze points of the participants. The minimal frame of this eye tracker allowed itself to fit on spectacles of the participants. See Figure3.5.

Figure 3.5 Pupil core eye-tracker

3.3 Testing

The purpose of this method is to test the research hypothesis. In order to do so, use the prototype, build an experimental setup to collect the quantitative and qualitative data required to test the hypothesis.

3.3.1 Recruiting participants

An invitation text was sent to network of friends, professors and acquaintances by email and social media platforms. Using convenience sampling, 15 participants were recruited for the experiment. There was limitation on recruiting unknown participant from Gjøvik town to prevent spreading COVID-19 infection. Since the experiment required the participants to be physically present in the experiment room, people not belonging to personal network were avoided.

Selection criteria

- Participant knows how to drive a car and holds a driving license

There were few cases where the people interested in the experiment had driven the car when practicing for the driving exam but had failed the exam. Such participant was considered based on years of practice-driving experience.

3.3.1.1 Recruited sample

15 participants having more than 9 months of driving experience were recruited. One participant could not join the experiment after experiment setup stopped functioning and rescheduling was not possible. In the end 14 participants were considered. Figure 3.6 shows how many participants belong to what range of year if driving experience.

3.3.2 Pilot testing

Once the experiment setup was complete, pilot tests were done with 3 different people. The pilot testing with first person helped understand that the dark room was not dark enough for the study. Therefore, the setup was moved into another room that had good conditions to create complete dark room. This test furthermore helped identify the correct eye tracker camera to capture the front scene also known as world view. The camera that captured wide scene was used. Next 2 pilot tests helped correct different errors in communication and experiment setup.

3.3.3 Experimental procedure

15 participants agreed to participate in the experiment out of several who came across direct invitation or social media post. The participants were asked to sit in the chair in the setup and then were briefed about procedure. A script was followed to explain the procedure in order to communicate the same message to all the participant so that there are no variations in what gets communicated.
See appendix 4 to read the Experiment guide. The participants then read and signed the consent form. See appendix 3 to read information letter and consent.

Then the participants were asked to adjust the chair to align with the steering wheel and the break-accelerator pad to feel at comfort according to their driving habit.

They were asked to wear pupil labs eye tracker and adjust the eye camera if needed. They were able to see their own eye through the pupil capture application when the main computer was connected to SVIVE monitor screen through HDMI. Screen calibration was done where concentric circles would move around the screen. The participants were asked to stare at the center of the circle. For few cases the method of calibration had to change to Single Maker due to unpredicted technical problems arising with the pupil capture application on MacBook pro.

There were two groups of driving footage clips. The video clips of respective group was added to VLC media player having video aspect ratio of 2:39:1. On asking if the participant was okay to proceed with task, these clips were played. The eye tracker and the GoPro3 camera recorded video while the driving clips were playing. When starting the driving footage for the test, a keyword "One, two three go" was said out loud so that the beginning of the test can be identified in the GoPro video recordings.

Group1	**Group2**
Training video1	Training video 1
Training video2	Training video 2
Task1 video	Task1 video
Task2 video: white icon	Task2 video: blue icon

Table 3.2 Experiment groups

Experiment with each participant took about 30 minutes. The eye tracker stopped recording for a participant therefore the experiment had to stop losing that participant. Therefore, the analysis is done for the 14 participants. At the end of the experiment, following questions were asked to each participant.

1. Do you have a driving license?
2. How many years of driving experience do you have?
3. Tell us your experience performing these tasks
4. Comparing the last two videos, which one caught your attention towards the pedestrian quickly? Why

The qualitative data collected form the answers was processed to find common themes. See section 4.3.2.

3.3.4 Eye-trackers for quantitative data gathering

Due to its advantages as mentioned in section 2.6 and usefulness in collecting precise quantitative data, eye tracker was used. One of the dependent measures: Effectiveness of the icon was calculated based on when the participant established gaze on the pedestrian icon. To capture this data, the product Pupil Core made by Pupil Labs was used. The software Pupil Capture that can be downloaded from the website of Pupil Labs, was used to calibrate the eye tracker and record the footage. The calibration was done on the left eye of the participants. The screen calibration method used 5-point calibration. For the cased where Single Marker calibration did not work and instead a marker-based calibration was required, a 9-point calibration was performed. To perform Single Marker calibration, a printed marker handle was used as shown in figure 3.7. The Start marker shown in figure 3.7 was held at 8 different locations on edges of the monitor screen. The participants were asked to stare at the center of the marker. To conclude the calibration on the 9^{th} point, the marker was flipped to show stop marker as shown in figure 3.7.

Figure 3.7 Start and stop markers for calibration

Sometimes even after proper calibration, the gaze markers shown in the Pupil Capture software are not very accurate. To see if there is any offset, the participants were asked to stare at the tip of a pen that was moved on monitor screen post-calibration. In case of big offsets, the eye was recalibrated.

Section 4.3.1 explains more about how this data was processed and analyzed in SPSS.

3.3.5 Assumptions

Conducting the experiment and involving the participants for the experiment assumes that the participants do not have any visual impairment. As stated by Ware (2004), some form of color vision deficiency is found in about 10% of the male population and 1% female population (Ware, 2004). Therefore, the next assumption while conducting the experiment is that none of the participants have any form of color vision deficiency or color blindness. This assumption affects the study if the type of color blindness is tritanomaly where the sensitivity to blue color is reduced. The color of the AR object used in the video footage is blue and white. Therefore, in case of blue AR object, if a participant has tritanomaly, the blue color might not be noticeable.

4 Result and Analysis

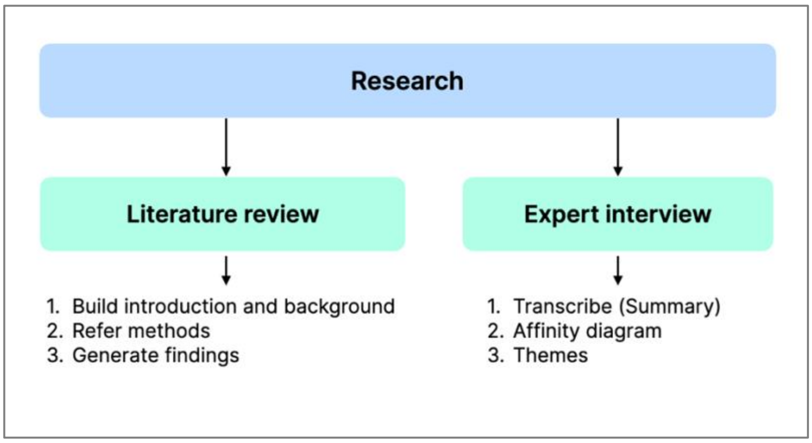

Figure 4.1 Process to analyze data gathered from literature review and expert interview

4.1 Result from literature reivew

The purpose of literature review was to build basis for the background, introduction and research question at start. Reading literature about AR technology helped gain understanding about not only advantages but also disadvantages. Appendix 5 shows the key research papers that helped frame the research problem of this thesis.

4.2 Expert interviews

The expert interviews conducted with two experts helped gain very specific understanding about the technology. The audio recordings of the interview were transcribed using *summarized* method referring to (Baxter, K., et al., 2015). This written summary was then analyzed to create affinity diagram. To do this the key points from the summary were written on sticky notes in Miro the collaboration platform. Then the cards were sorted. The cards having common theme were placed together and were given a name representing that category. Figure 4.2 shows all the categories formed by analyzing and sorting the cards. These themes are elaborated below

1. **Limitations**
   a. When it comes to using AR HUDs in cars, the light conditions may not support use of technology. If drivers use sunglasses in cars, that can badly affect the visibility of objects on HUD.
   b. User of Head Mounted Displays is ergonomically not sound to use inside cars. These can also cause neck injuries.
   c. Showing alerts in HUD can distract the driver when the driver can clearly see the obstacle clearly.

2. **Things to keep in mind while designing for AR HUD**
    a. Minimal approach should be followed in order to avoid information overload. Driver should not be required to read information, instead information should be easy to understand quickly.
    b. User of Head Mounted Displays is ergonomically not sound to use inside cars. These can also cause neck injuries.
    c. Showing alerts in HUD can distract the driver when the driver can clearly see the obstacle clearly.
    d. Graphics of AR object should not obstruct the view.
    e. Persistently showing information should be avoided
    f. Before bringing new technology, it should be verified that it does not reduce the safety.

3. **Brightness issues and considerations**
    a. Reflection is closely tied with contrast which is the biggest problem. The light coming from headlights or taillights of other vehicles, streets lights create glare on the windshield of the car. Reflective street signs also glow brightly when headlight of a car incidents on the reflective surface. When an AR object is projected or displayed on the windshield of a car, in order to see it clearly there has to be enough contrast between the background of the AR object and the object itself. With bright lights being in the background, establishing enough contrast is very challenging.
    b. When driving form dark environments to light environments, the brightness of overall background shifts. One cannot keep constant color value of AR objects on the windscreen. Therefore, the lightness of the color of AR object need to change based on background to maintain certain level of contrast.
    c. Every individual has different preference when it comes to brightness of the interface. For the contrast ratio of background and AR object to be useful for every individual driver, there should be an affordance to change the brightness of AR objects. However, if a driver sets the brightness to very high value, the amount of light in the car can reduce night vision for surrounding area outside the car. Standards need to be set if AR HUDs are to be installed in car.

4. **Showing obstacles in AR HUD**
    a. Information related with the obstacle should be attached to the obstacle graphic.
    b. Obstacle should not be obstructed completely with graphic
    c. Obstacle can be related with change in landscape or slippery roads. This should be included as well.

5. **Color of the AR object**
    a. The color depends highly on the background.
    b. Blue has been found to be good as it does not tire you in dark conditions and helps the mood. Undertones of blue can be used on AR HUD. The color should be neutral color and not red or green indicating as meaning with these colors is well established.

6. **Task based approach**
    a. Task based approached should be followed which can help evaluate if certain information is really helpful to complete that task in that context.

7. Pros and Cons

a. Pros:
   i. AR HUD can reduce distraction potential.
   ii. Can be more useful in semi-autonomous to autonomous cars.
   iii. Can be useful to highlight objects In low visibility conditions.

b. Cons:
   i. It can be tempting to add more information which can lead in information overload.
   ii. Cannot be used in nighttime as they can reduce night vision.
   iii. People can get bored if they cannot manipulate the system.

8. Dos and Don'ts

a. Dos:
   i. Verify if information to be displayed in HUD supports the task in given context.
   ii. Show information in field of view (FOV).
   iii. Design the alert in meaningful way
   iv. Verify if new technology/feature does not reduce existing safety of the system. Then only use that technology/feature.

b. Don'ts:
   i. Persistently show information
   ii. Obstructing the view in front
   iii. Show too much information
   iv. Very bright colors on HUD

Figure 4.2 Themes from expert interview

4.3 Experiment

Qualitative and quantitative data collected from 14 participants. Quantitative data was derived from the video footage. There were two video footages in consideration. The first one captured from the eye tracker that showed what does a participant see in from of them on the monitor screen. This did not have audio. The second footage captured the brake pedal. Qualitative data was gathered from answers given to the questions asked at the end of the experiment.

To get desired quantitative data, the gaze data, time taken to establish gaze on pedestrian and reaction time was calculated.

To calculate the time when the first gaze was established on the pedestrian in Task 1 and task 2 videos, the recording was exported into mp4 file using Pupil Player software. The start time of the of driving footage from eye tracker recording and the start time from GoPro recording were matched and put together in single frame in Adobe Aftereffects. This step helped identify the timestamp of pressing brakes after establishing gaze on the pedestrian from task videos.

To calculate time taken to establish gaze on pedestrian, the timestamp of pedestrian appearing on the video and timestamp of first gaze established after pedestrian was introduced in the video was found. Then these timestamps were subtracted to give time taken to notice the pedestrian. The outcome is the dependent variable 'Time taken to establish the gaze'.

To calculate the reaction time, the timestamp of when the brakes were pressed after establishing the gaze on the pedestrian were found. By subtracting these two times, the reaction time was calculated. The outcome is the dependent variable 'Reaction time'.

The qualitative data was written in an excel sheet. Figure 4.3 shows how collected data was processed.

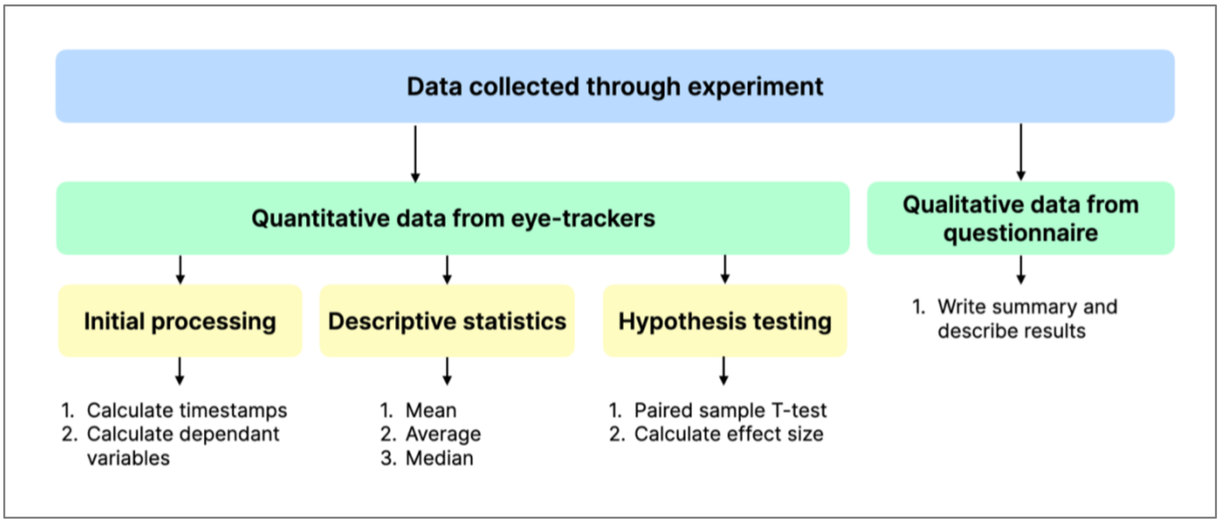

Figure 4.3 Process to analyze data gathered from experiment

4.3.1 Analysis of quantitative data

An excel sheet enlisting the value of all dependent variables for each participant was imported in SPSS software. The participant ids were also grouped. There were two groups based on the color of pedestrian icon used in the task video footage of the experiment. While calculating the values of dependent variables for each participant it was also observed that technical problems had occurred. Due to this the reaction time of first task for 5 participants and reaction time for seconds task of two participants could not be calculated. On account of the same reason the time taken to notice the pedestrian in task 1 could not be calculated for one participant. The rest of the available data was analyzed in SPSS as follows.

Time taken to notice the pedestrian in task1 was encoded as: T1_time

Time taken to notice the pedestrian in task1 was encoded as: T2_time

Time taken to notice the pedestrian in task1 was encoded as: T1_R_time

Time taken to notice the pedestrian in task1 was encoded as: T2_R_time

4.3.1.1 Descriptive statistics

The descriptive statistics help understand nature of the data. In SPSS, the mean, median, median, mode, standard deviation, skewness was calculated. Figure 4.4 shows the values for descriptive statistics.

Statistics

		T1_time	T1_R-time	T2_time	T2_R-time
N	Valid	12	8	13	11
	Missing	1	5	0	2
Mean		1.6667	1.8750	.6154	2.0909
Median		1.5000	2.0000	.0000	2.0000
Mode		1.00	3.00	.00	2.00
Std. Deviation		.77850	1.12599	.76795	2.38556
Skewness		.719	-.488	.849	2.840
Std. Error of Skewness		.637	.752	.616	.661

Figure 4.4 Descriptive statistics

The mean time taken to notice the pedestrian when no AR icon was used was 1.6667 seconds. The mean time taken to react when pedestrian was seen by the participant was 1.8750 seconds. For task2 where the pedestrian was cued using AR icon, the mean time taken to notice the pedestrian was 0.6134 seconds and the mean time taken to react and press brakes or decelerate was 2.0909 seconds.

The standards deviation of T1_R-time and of T2_R-time are very high compared to that of T1_time and T2_time. The samples in T1_R-time and T2_R-time are more spread which can be due to the missing values.

Based in the skewness values it can be stated that T1_time, T2_time and T2_R-time are right skewed. T1_R-time is left skewed.

4.3.1.2 Hypothesis testing

Hypothesis1 (H_1): Use of AR objects helps quickly notice the pedestrian.

Hypothesis 2 (H_2): Use of AR objects increase the response time of the driver.

4.3.1.2.1 Paired sample T test

A paired sample T test was performed on T1_time with T2_time and T1_R_time with T2_R_time. Refer figure 4.5 to see the results. A Paired sample T test helps identify if there is a significant difference between the two variables for the same subject.

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	T1_time - T2_time	1.16667	.71774	.20719	.71064	1.62270	5.631	11	.000
Pair 2	T1_R-time - T2_R-time	-.25000	2.49285	.88135	-2.33407	1.83407	-.284	7	.785

Figure 4.5 Result of paired sample t test from SPSS

The significance level decided in this thesis is 0,05. Paired sample T test gave the significance 0.00 for Pair 1. For Pair2 the significance is 0.785.

Significance value for Pair 1 is 0.000 which is less than 0.05. The result of independent sample t test of Pair 1 implies that there is a significant difference between the two groups. This further imply that the probability of AR object for the pedestrian causing reduction in time taken to notice the pedestrian is significant.

Significance value for Pair 2 is 0.785 which is greater than 0.05. This implies that there is no significant difference in T1_R_time and T1_R_time. Which further implies that there is no significant effect of the AR object on reaction time.

4.3.1.2.2 Calculation of effective size

In order to ensure that the differences in the means calculated in the t test are not merely due to chance, the effect sizes for each part were calculated using Cohen's d test in SPSS. Cohen's test imply how big is the difference in two groups.

Paired Samples Effect Sizes

			Standardizer[a]	Point Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper
Pair 1	T1_time - T2_time	Cohen's d	.71774	1.625	.733	2.488
		Hedges' correction	.74343	1.569	.708	2.402
Pair 2	T1_R-time - T2_R-time	Cohen's d	2.49285	-.100	-.792	.598
		Hedges' correction	2.63713	-.095	-.748	.565

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

Figure 4.6 Result of Cohen's d test from SPSS

The Cohen's d value for Pair 1 is 0.71774 which lies in the range of medium effect size defined by Cohen. This indicates that there is medium difference in the means of T1_time and T2_time.

The Cohen's d value for Pair 2 is 2.49285 which lies in the range of large effect size defined by Cohen. This indicates that there is large difference in the means of T1_time and T2_time.

4.3.2 Analysis of qualitative data

The qualitative data obtained from asking questions to the participants after the experiment was analyzed. Following questions were asked after the experiment

1. Do you have a driving license?
2. How many years of driving experience do you have?
3. Tell us your experience performing these tasks
4. Comparing the last two videos, which one caught your attention towards the pedestrian quickly? Why

The participants had years of driving experience that could be distinguished into 3 groups as follows.

Group	1-Early stage	2-Moderately experienced	3-highly experienced
Years of driving experience	1-5	6-20	21 and above

Figure 4.7 Grouping of participants based on driving experience

A pie chart was generated to indicate responses for question 3. The result looks as below

Figure 4.8 Number of participants for each group if driving experience

7 participants reported that the video having AR object for the pedestrian caught their attention towards the pedestrian quickly. 5 participants reported the opposite. 2 participants did not feel any difference and reported that in both the videos their attention towards the pedestrians was directed quickly.

When asked why they thought their attentions was grabbed quickly, interesting comments were given by the participants. The majority of participants admitted that the AR icon was the reason. A few of them stated that they could not guess what the icon was and confused it as a different street sign or an unrecognizable object. By contrast, after some time understood that it was in fact a pedestrian.

Among those who responded that the first video V1 caught the attention to pedestrians quickly had mixed reasoning. Few of them noticed the pedestrian coming near the road clearly either due to good light conditions or due to the fact that the pedestrian was closer to the car therefore big as that compared with the second video. Two participants reported that the actually human felt more real. One of these participants also mentioned that with real person, they felt more responsibility towards not hitting it.

The participants who mentioned that there was not difference between two videos had no specific reasoning for why they felt no difference.

5 Discussion

This thesis conducted the experiment to study the how effective are AR objects in alerting the driver about obstacles on the road. Section 4.3.1.2 indicates that Hypothesis 1(H_1) holds true since there was significant difference in T1_time and T2_time. Hypothesis 2 (H_2) has not been proven true since no significant difference was found in T2_time for group1(having white icon) and T2_time for group 2(having blue icon).

Although the obstacle specified in this study is a pedestrian, a pedestrian alone does not represent complete set of obstacles. As presented in section 4.2, there is scope to create taxonomy of all possible obstacle and create design pattern for each one. Therefore, this particular thesis experiments very narrow part of obstacle detection and making is visual for driver to notice it.

Based on the literature and expert interviews, there are two ways to reduce perceptual tunneling. First one being, avoid persistently showing information on AR HUD. Therefore, take away the AR information once the context is over and purpose is fulfilled. The second one is, combining visual and audio or tactile sensory alerts to increase situation awareness when needed. The saliency of the AR object, pedestrian, was not affected by change in color according to what results show.

Based on the literature review and expert interviews, following are the recommendations to take in account while designing for AR HUD and avoiding perceptual tunneling

1. Ensure the AR information is clearly visible from POV of the driver taking in account some head movement done while looking around.
2. Establish enough contrast between background and AR object hence keep the brightness of AR HUD adaptable.
3. Allow the user of the driver to change the brightness setting up to the limit where AR information is still readable with enough contrast
4. Choose colors of AR object in a way that they account for color vision deficiency
5. Avert displaying chunk of information persistently
6. Design information in a way that it can be understood by scanning and does not require reading
7. Critically think if the AR information supports the task at hand in given context

As mentioned in section 5.3 - limitations, the number of experts who participated in expert interview were two. In order to get more and rich insights the interview, the experts who have worked specifically in automobile domain and on AR HUD systems should be involved. It was planned to have the experts who work in well-known car companies that have come up with AR HUD features. Due to no response given by the companies approached, those insights could not be captured.

While listening to audio recordings of the expert interview, it was observed that there were many places where nudging should have applied. Asking why could have revealed new insights from expert rather than taking in surface level information from them. Nudging or 5 Whys methods should be considered for expert interview in future work.

Due to ongoing COVID-19 restrictions the risk of inviting many and unknown people to participate in the experiment was not possible. In conditions where there is not pandemic and no restrictions are active that limit meeting people, at least 40 people would be recruited. Looking at the sample, there are more participants having driving experience between 5 to 10 years of driving experience. After that the most participants have driving experience in range of 1 to 4 years. There are only two participants having 22 and 38 years of experience. The results calculated using this sample indicate the behavior of people having little to moderate driving experience. More participants having more than 10 years of driving experience should be recruited to make the sample well distributed across all levels of experience.

One of the arguments build in this thesis is that persistent display of speed and navigational information on HUD causes perceptual tunneling. In order to keep the HUD interface simple, navigational information was skipped in the experiment. Instead, only speed information was merged with the video footage. To make the experiment condition more realistic the navigation information should also be considered. Navigation information includes the arrows indicating whether to turn left or right or go straight and how far is the next turn. Side effect of not having any navigational information was that the participant had no clue where the car will turn next and felt lost and uncomfortable. Since one would not always use the map function or navigation feature in car and instead can just drive the car based on learned routes, the decision of not having navigation information was taken. For future work the comparison should be observed by having navigation information and by not having navigation information.

The video footage was taken in March 2021 in Norway when the snow on the road is fairly gone. Nighttime was chosen to capture the low visibility condition. Low visibility condition also resembles with fog. In Norway and in many other countries, during winter the days are short and low visibility conditions persist during the day with snow all around. Taking video footage of such conditions should also be done since this is a low visibility condition.

The point of view in video footage used in the experiment is not how a driver sees the view from the car. As the camera was fixated at the center of the car, the participant looking at the video has altered view of the road scene than the original one. Fixing the GoPro camera on head or neck of the driver to capture driving footage can work. In contrast, this can make video footage very unstable and jerky due to bumpy roads. Therefore, this way was not explored. A better way to capture video footage from driver's point of view should be followed to make it a realistic driving experience.

Few participants commented that they thought the second footage showed a notice or warning of pedestrian and not actually a pedestrian. If this perception holds true for many people, it means that there needs to be a way to convey that the cue is a real person and not just an animated icon.

The results are based on inductive reasoning and the conclusion holds true for specific sample of participants in consideration. As mentioned in section 1.2 - Assumptions, some form of color vision deficiency is found in about 10% of the male population and 1% female population Ware, C., (2004). Therefore, the results can vary on inclusion of wider sample group having variety of driving experience, age, color blindness factor and strength of vision.

5.1 Validity

The internal validity of the experiment was ensured by two means in this study referring to (Leedy and Ormrod, 2015).

1. **A controlled laboratory study**
   The experiment was conducted in laboratory setting keeping all factors same for all the participants. An exception of this could be the method of calibration where single marker method was used in few cases. This should not have major effect on the outcome since 9-point calibration which is a thorough measure calibration was used.

2. **Triangulation**
   Triangulation method uses multiple sources of data collection in hope that it will converge to support the hypothesis (Leedy and Ormrod, 2015). The result of the experiment carried in this study are supported by both quantitative and qualitative data.

A variable affecting the internal validity of the experiment is the video footage in task1 and task2 itself. The scenes in the video were at different location and had different lighting condition. The first scene was in city area having well-lit roads and the driver had better opportunity to look at the pedestrian even before the pedestrian came near the road as the car was turning left, and the pedestrian was coming from the right side of the road. Whereas the second scene was recorded on roads that were outside the city and crowded area. For better comparison of AR object with no AR object for pedestrian detection, both the scenes need to be fairly similar. Nonetheless, the decision to keep different video footages was not changed as usage of same video footages having one without any AR object and one with AR object would have learning effect. This way the participant might have learned when and from where the pedestrian comes on the road. This further could have affected in having earlier time to establish gaze at AR object. To deal with this conflict, for future studies, many incidences of pedestrian coming on the road should be captures. Having footage of pedestrian coming from the right side of the road, left side of the road, being close to the car and far from the car these variations can create good set of test footages.

5.2 Reliability

The study participants were recruited with convenient sampling. Due to COVID-19 restriction only the participants from close circle and those working in same campus were recruited. There is sampling bias when it comes to recruiting participants for the experiment.

Some extent of response bias can be present in the result of the experiment. The participants were known personally and would not have responded naturally.

There is a change of recency effect when participants were asked which video caught their attention to the pedestrian quickly. The video having AR object was presented at the end therefore there is a chance that they recalled the last video. If that is the case, it directly affects the result of qualitative data.

5.3 Limitations

One of the major limitations of the expert interview and the experiment is the number of participants. The expert interview was done with 2 experts as only two experts responded among all the experts contacted so far. For the experiment, the recruitment of participants can have personal bias since the people from personal network were asked to participate. While doing this thesis, COVID-19 pandemic precautions were to be followed strictly. Due to this, there was limitation to invite any or unknown people from same town to participate in the study.

The color of the icon and shape was defined based on what was found from the literature review. There are other features of the AR objects that could be explored and tested such as more colors, various line thickness. If thought from the multimodality and universal design aspect, the AR object could have been combined with audio alerts to test which option is more effective. Exploring more featured implied more group. Since the participant number was going to be limited, the participants in group would have reduced. Less participants would have resulted in insignificant data. Therefore, only color variation was explored. Only color may not influence the overall effectiveness of the AR objects.

The eye tracker calibration was done using screen marker which was observed to be most stable method compared to single marker calibration. Even after using the screen marker method the actual gaze point differed by a few centimeters. This was consistent in all footages captured by the eye tracker. This instrument error might have influenced directly on the values of timestamp recorded for quantitative analysis.

Some of the participants form the experiment were wearing binocular glasses which indicate they needed an aid to see while driving. The study did not take any test to see if participants have vision deficiency or even color vision deficiency. The results assume that all participants were able to see the AR object under normal vision conditions. Whereas in real case the vision deficiency might have altered the time taken to notice the AR object in the video.

Finally, the result can be improved by taking in consideration recommendation mentioned in discussion chapter. There is more scope to expand this study as mentioned in future work

6 Conclusion

This study focuses on finding effectiveness of AR objects for obstacle cuing. Through literature review advantages and drawbacks of the AR HUD as a technology were identified. Expert interview was conducted with 2 experts. This interview revealed different themes related to what to take care of when designing for AR HUDs, pros and cons of the technology, brightness issues and possible precautions to take, color of AR objects, task-based approach for proposing feature on AR HUD and dos and don’ts when it comes to designing for AR HUDs. The literature review combined with expert reviews helped decide the design features that can be applied to define salience of AR object used for queuing.

The experiment conducted in this study with 14 participants partially confirms the hypothesis. The results clarify that usage of AR cues helps get attention towards the pedestrian, however, this does not directly imply that it reduces the response time. The data captured from eye tracker revealed that participants established gaze at pedestrian quickly when it was cued using AR objects. The response time merely shifted early due to the fact that the gaze was established on the pedestrian early. No direct relation was found between AR cuing and change in response time.

The participants were divided in three groups viz 1-4 years experiences, 5-20 years experiences and 21 and above years of experience. Most of the participants belong to the second groups that is 5-20 years experienced. Therefore, the results incline towards behavior of this particular group. Although more studies should be conducted to involve drivers having more years of driving experience. Using AR objects to highlight the pedestrian in nighttime condition where surroundings were dark was appreciated by majority of the participants. In contrast, a highly experienced drivers and few moderately experiences drivers expressed that seeing real pedestrian still felt more realistic than the one cued with AR object. A few drivers also stated that the AR object obstructed the view therefore should not see what was behind the AR object.

It can be concluded that AR is useful technology to effectively alert the driver. However, to prevent or reduce the perceptual tunneling effect, the information should only be shown for the right context. Once the purpose is achieved the information should be taken away from AR HUD and persistently showing the information should be prohibited. If looked at the saliency of the AR object used in this study, variation of the color did not change the saliency of AR object.

6.1 Future work

The saliency of AR object does not limit only to the color variation. Combination of different shape, line thickness, colors, animations should be explored to see if these affect the saliency of the AR object. Inclusion of more early-stage drivers and very experienced drivers should be done in the experiment.

This study takes in consideration one independent variable to predict the usefulness of the AR technology for obstacle cuing.

To conduct similar study, the manual work of calculating timestamps should be avoided. Instrument error should be removed by even more calibration iterations or another eye tracker that gives exact gaze points. A method to automatically register brake or deceleration trigger will reduce human error of matching two video footages and calculating response time.

For future work studies can be conducted to answer following questions

1. Can visual AR cue with paired with audio be effective way to alert the user about obstacle
2. What is an effective way to cue all kinds of obstacles such as pedestrian, animal, other objects in order to make the driver understand it's meaning quickly?
3. What colors should be used on AR HUD in order to make it effective for all types of color vision deficiencies?
4. What all factors account to perceptual tunneling and how to reduce perceptual tunneling?

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Appendices

Appendix 1: Information letter and consent form for expert interview

Appendix 2: Expert interview guide

Appendix 3: Information letter and consent for experiment

Appendix 4: Experiment guide

Appendix 5: Literature review table

Appendix 1: Information letter and consent form for expert interview

Are you interested in taking part in the research project

" Augmented Reality HUDs in car for obstacle detection"?

This is an inquiry about participation in a research project where the main purpose is to "find better way to visualize obstacle cuing in Augmented Reality Head Up Display in cars ". In this letter we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project

Augmented Reality has gained much popularity in past decade. The automobile industry is experimenting with this technology to make car driving a better experience. The purpose of this project is to study use of AR objects on Head Up Displays of cars for obstacle detection. This is part of the master's thesis of Interaction Design program at NTNU Gjøvik.

Who is responsible for the research project?

NTNU is the institution responsible for the project.

Project supervisor: Ole E. Wattne

Email id: ole.wattne@ntnu.no

Phone number: +47 93445885

Why are you being asked to participate?

The individuals selected for this interview are those who satisfy any one of the following criteria

- Have worked in automobile industry for more than 5 years
- Worked in a department that deals with research and design of car system
- Has a position of taking design decision or creating designs in automobile industry?
- Have done research and/ or written papers on topics related to AR HUDs in cars or similar environment.

In total, 5 number of individuals were asked to participate, and you are one of them.

What does participation involve for you?

This interview will help get insights into important information that is required to show to a driver related with obstacle detection. For this, I will ask you questions about your experience in working with AR in automobile industry. I will also record the audio of our conversation and take notes in my notebook if necessary. This interview will last for approximately 45 mins.

Participation is voluntary

Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no

negative consequences for you if you chose not to participate or later decide to withdraw.
After 31st December 2021, the data will be either anonymized or deleted on this date.

Your personal privacy – how we will store and use your personal data

We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). Participants are not explicitly identifiable in thesis report.

How can you contact me to correct the data that you have shared with me?

- The project supervisor of the project will have access to the personal data and data collected in this process.
- The collection of the data will be stored on the hard drive that will stay in a locker at NTNU/ Ole Wattne's office, to which only I and the project supervisor has access.
- In order to get access to the data, the participant can directly contact myself or project supervisor.

What will happen to your personal data at the end of the research project?

The project is scheduled to end on 1st June 2021. After this, the data will be anonymized, and this anonymized data will be stored securely at NTNU up to next 3 years. After anonymizing the data, it will not be possible to remove the data belonging to a specific person because it is anonymous.

Your rights

So long as you can be identified in the collected data, you have the right to:

- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?

We will process your personal data based on your consent. Based on an agreement with NTNU, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?

If you have questions about the project, or want to exercise your rights, contact:

- Ole Edward Wattne
  Email: ole.wattne@ntnu.no
- Our Data Protection Officer: thomas.helgesen@ntnu.no
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Yours sincerely,

Ole Edward Wattne
Project Leader
(Researcher/supervisor)

Chetana Pandit Karande
Student

Consent form

I have received and understood information about the project *[insert project title]* and have been given the opportunity to ask questions. I give consent:

- ☐ to participate in the interview

I give consent for my personal data to be processed until the end date of the project, approx. *[insert date]*

(Signed by participant, date)

Appendix 2: Expert interview guide

I Introduction

Thank you for taking out your valuable time for this interview. As you may have read earlier that this interview is a part of research process where I want to understand important aspects of AR in automobile, also study safety aspect of this for the driver. In this interview I want to focus on your expertise related with this technology and design of the interfaces. In this interview you are the expert, and I will be getting insights from what you inform me. There are no right or wrong answers to any questions. This Interview should take no more than an hour. This interview is voluntary, and you can choose to leave anytime you want. Everything you say will be anonymized and the personal data that I collect will be removed from the storage on 1st June 2021 (will anonymize the data right after completing the project and then delete the data no later than 1st June 2021).

Finally, I want to ask if I can record the audio of our conversation, as it will help me get detailed notes later when I listen to it, so that I can focus on our conversation rathe that writing it simultaneously. Is it okay?

Questions

1. Have you worked on car interfaces related to AR HUD?

    Can you describe the process?

    Which car?

    Can you compare the experience with a car not having AR or HUD? Tell me about what you think about this technology coming in automobile industry.

    Do you see any drawback in using this tech?

2. What are your views on having AR objects in windshield of car?

    The advantages

    Disadvantages

3. What comes to your mind when thinking about AR being used on HUDs for pedestrian or obstacle detection?

4. Do you think AR should be used in obstacle detection?

    what are pros and cons of this?

5. What are your thoughts when we consider safety of the driver and use of AR to show objects on HUD?

6. Can you tell me about why is this tech coming to the vehicles right now?

7. Have you worked on obstacle cuing interfaces?

    Have you explored any other ways of visualizing the same in AR?

9. Call you tell me what advantages and disadvantages you have identified of these visuals at this moment?

9. What should be considered while designing for obstacle detection using AR?

    Can you tell in terms of does and don’ts?

    When it comes to nighttime driving, are there any special conditions to take care of while using AR HUDs?

10. Have you developed or already follow any guidelines when it comes to cuing? Or in AR?

Wrap up

1. Do you own a car with AR HUD? What is your personal opinion on this technology?
2. How would you make an AR feature on the car more desirable to the users?
3. Do you know anyone who has worked in this area that I can interview?

With this I have covered all the questions I asked to you. Do you have anything to add that you feel we have not covered?

Then I want to thank you again for being here today. Learning about your perspective on this is going to help me create better solution for obstacle cuing.

If you have any question, you are more than welcome to get in touch with me. I also want to ask if it is okay to contact you in case, I have another question or something is unclear, is that okay?

Appendix 3: Information letter and consent for experiment

Are you interested in taking part in the research project

"Augmented Reality HUDs in car for safety" ?

This is an inquiry about participation in a research project where the main purpose is to find better way to visualize obstacle cuing in Augmented Reality Head Up Display in cars. In this letter we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project

To study use of AR objects on Head Up Displays of cars. This is part of the master's thesis of Interaction Design program at NTNU Gjøvik.

Who is responsible for the research project?

NTNU is the institution responsible for the project.

Project supervisor: Ole E. Wattne

Email id: ole.wattne@ntnu.no

Phone number: +47 93445885

Why are you being asked to participate?

The individuals selected for this interview are those who satisfy any one of the following criteria

- Are eligible to drive a car and hold a driving license
- Are older than 18 years
- Have experience driving a car

In total, 11+4 number of individuals were planned to ask for participate, and you are one of them.

What does participation involve for you?

Your performance in the tasks will help me get data to analyze and test my hypothesis. You will be offered a small snack at the end of the study.

Participation is voluntary

Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw. After 31st December 2021, the data will be either anonymized or deleted on this date.

Your personal privacy – how we will store and use your personal data

We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). Participants are not explicitly identifiable in thesis report.

How can you contact me in case you want to correct data that you have already given me?

• Contact me at chetanak@stud.ntnu.no or Ole Wattne (project supervisor).

• The project supervisor of the project will have access to the personal data and data collected in this process. The collection of the data will be stored on the hard drive that will stay in a locker at NTNU/ Ole Wattne's office, to which only I and the project supervisor has access. In order to get access to the data, the participant can directly contact myself or project supervisor.

How will this experiment be conducted?

1.You will be asked to sit in experiment setup comfortably so that you can see the monito screen completely and can reach the steering and accelerator-break-clutch pad. The place will be sanitized by moderator (myself).

2.You will be asked to wear an eye-tracker that has two cameras. First camera tracks the movement of your eye-pupil and the second captures the view in front of your eyes that the scene your eyes are seeing on the computer screen. The calibration will be done by adjusting eye-tracker and field of view in front of you. The video of what you see in front of you and the eye movement will be captured. The captured video of your eyes is very low-resolution video and does not identify as biometric information to find you identity.

3.I will start recording video using the go-pro camera to only capture your foot pressing brake pad during the test.

4.You will be shown 4 driving video feeds. The scene involves road on which a vehicle is moving during nighttime. You are to observe the videos. You have to pretend like you are driving the car. You can put your hands on the steering and foot in brake pad to get the feel of it.

5.You are required to respond to what is happening in the video using breaks and steering wheel. For example, if the car speeds up that speed limit you can press the breaks. Of you see pedestrians coming in the road, you can press the breaks. The video may not respond to your actions, but I will make note of it for study.

6.At the end of the task, you may be asked a few questions that requires you to answer based on what you saw on the screen and your interpretation of the same.

What will happen to your personal data at the end of the research project?

The project is scheduled to end on 1st June 2021. After this, the data will be anonymized, and this anonymized data will be stored securely at NTNU up to next 3 years. After anonymizing the data, it will not be possible to remove the data belonging to a specific person because it is anonymous.

Your rights

So long as you can be identified in the collected data, you have the right to:

- access the personal data that is being processed about you

- request that your personal data is deleted

- request that incorrect personal data about you is corrected/rectified

- receive a copy of your personal data (data portability), and

- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?

We will process your personal data based on your consent. Based on an agreement with NTNU, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?

If you have questions about the project, or want to exercise your rights, contact:

• Ole Edward Wattne

Email: ole.wattne@ntnu.no

• Our Data Protection Officer: thomas.helgesen@ntnu.no

• NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no)

or by telephone: +47 55 58 21 17.

Yours sincerely,

Project Leader   Student (if applicable)

(Researcher/supervisor)

Consent form

I have received and understood information about the project *[insert project title]* and have been given the opportunity to ask questions. I give consent:

☐ to participate in the interview

I give consent for my personal data to be processed until the end date of the project, approx. *[insert date]*

(Signed by participant, date)

Appendix 4: Experiment guide

Script
Thank you for taking out your valuable time for experiment. This experiment is a part of research where I want to understand how effective the use of in cars AR Head Up Displays is while driving.

In this experiment, I will ask you to perform a few tasks related with driving. This does not need any special knowledge. If you have driven a car then this is going to be easy for you.

This experiment should take no more than 25 mins. This experiment is voluntary, and you can choose to leave anytime you want. Everything you say will be anonymized and all this data will be removed from the storage on 1st June 2021 (will anonymize the data right after completing the project and then delete the data no later than 1st June 2021). There are no right or wrong answers to any questions.

In the experiment I am going to play different clips of driving footage on the big monitor screen. There is steering and break-pad in front of you, you can adjust your chair to align the steering and break-pad now. When I play the driving footage, you have to pretend like you are driving the car. You can use the steering to turn right or left. You will be seeing the speed limit and speed information on the screen. If you feel the car in the video is going too fast you can use break and if you feel the car is going too slow you can press the accelerator. In case of emergency, you can hit the brakes hard. Now the video might not respond to your actions because it is pre-recorded. But I will make not of your actions.

I am using an eye tracker and a video camera. The eye tracker is going to capture movement of your eye. This is so that I know where you look on screen. This data cannot be used as biometric data. The camera captures view of your foot pressing accelerator/break/clutch. This video is not going to capture your identity. The footage is only going to be used to capture the time when you press something.

Before we start, I want to ask if this is okay with you before we continue with tasks. Is it okay with you?
- Now ask them to sign the consent form.

Steps – checklist

Pre experiment
- Make sure monitor power is connected well
- Curtains are closed
- Go-pro is charged well
- Consent form is printed
- Sanitizers, mask is in the experiment room
- Treats are arranged
- Correct video playlist is opened in VLC player
- Select right aspect ratio in VLC media player

At the time of experiment

- Put on Eye trackers
- Close the door
- Connect monitor HDMI to personal laptop
- Adjust the Eye camera
- Look top, down, left, right
- Adjust the green circle around the eye. Make sure id=1 in pupil capture
- Select calibration screen to monitor screen
  Say to the participant - "Now you will see concentric circles on screen. You have to stare at the center. Then the circle will move to different locations on the screen. Follow the circle and stare at the center. We might have to perform this a few times to get it correct. Are you ready?"

- Click on calibrate in Pupil Labs s/w
- Move a pen on screen and ask them to follow that finger.

- Connect the HDMI to mac-mini
  "Now I am going to play the driving videos. Are you ready?"
- Hit record on GoPRo
- Hit record on eye-tracker
- Say 3..2..1..Go...Hit play on VLC
- Let 4 videos play one after other
- After last video – stop recording on eye tracker
- Stop recording on camera
- Open curtains from behind
- Open excel sheet and go through questionnaire

Questions

1. Do you have a driving license?
2. How many years of driving experience do you have?
3. Tell us your experience performing the tasks
4. Comparing the two videos, which one caught your attention towards the pedestrian quickly? Why?
5. Wrap up: Do you have questions for me?

Appendix 5: Literature review table

Part1

Literature part 1

Source	Advantages	Disadvantages	Solution
Effects of image distance on cognitive tunneling with AR HUDs. Joseph Pullukat, Shinichi Tanaka, Jiaho Jiang	increased eyes on the road, reduced visual accommodation	AR HUDs make the actual outside scene secondary because primary scene is AR information Same amount of information as aviation screens is not acceptable to show to car drivers HUD and outside world- The brain cannot control concurrently process both these data sets causes cognitive tunneling	AR automotive HUD must strengthen the driver's ability to recognise important items in the outside environment and not hinder its perception Use conformal graphics- that overlay conform to the outside world
Ergonomic Guidance of Head-Up Display User Interface during Semi-Automated Driving Kibulam Park, youngjae Im	HUD improves driving performance more than the head down display and has higher preference Trust confidence and predictability factors also tend to increase if HUD is combined with Speech & is multimodal This reduces driver's visual distraction and improves cognitive judgement	reduces response time and increases the likelihood of detecting other hazards More the information on windscreen, more the subjective workload	There is need to reduce the recognition errors of displayed images and minimise the distraction. The number of information to be shown on HUD should be fewer than 6 symbols
Augmented reality HUDs effect on diver's spatial knowledge acquisition Nayara De Oliveira, Dina Kandil, Joseph L Gabbard	driver can offload tactical (route following) and strategic aspects(route planning) of navigational tasks	drivers do not develop as much environmental spatial knowledge as that with paper maps	It is important to develop cognitive map as it is a social function results suggest that simple, screen fixed designs may indeed be effective in certain contexts
Simulation based evaluation of an in-vehicle smart situational awareness enhancement system Andreas Gregoriades, Alistair Sutcliffe	Can improve situational awareness Information rich system showed there was more situational awareness	Does not include hazard that are not directly visible to the driver only accounts the situational awareness for first 2 levels of SA model (?)	Information rich display - radar style display minimal information display - arrow hazard indicator
World Fixed AR HUD for smart notifications Mainak Biswas, Shili Xu	Smart notifications help driver	Conventional displays may not urgently and reliably warn driver without distracting from scene in front Auditory and haptics display may not convey information adequately and immediately	Proposed algorithms that shows smart notifications Alters the scene to show break lights of vehicle in the front to alert the driver

Part2

Literature part 2

Source	Advantages	Disadvantages	Solution
Augmented Reality Cues and Elderly Driver Hazard Perception Mark C Schall Jr., Michelle L Rusch, John D Lee, Jeffrey D Dawlson, Geb Thomas....	AR cues show promise for improving elderly driver safety by increasing hazard detection AR cue may help direct driver's attention to roadways hazard improve target detection and reduce collision involvement Provides informative annotations AR cues improved participant response rates and response times relative to uncued conditions	intereference with drivers perception of secondary objects and tasks, thereby decreases accuracy and increases response time. Divided attention High false alarm rates can irritate drivers and reduce trust. This can lead driver to ignore, avoid alarms totally	
Augmented Reality Interface design approaches for goal directed and stimulus-driven driving tasks Coleman Merenda, Hyungil Kim, Kyle Tanous, Joseph L. Gabbard,...	AR based displays deliver information to drivers while still maintaining lower level of mental workload help maintain gaze on roads resulting in quick reaction time, improved task performance	increase in divided attention Added cognitive load, task complexity increases Cognitive /attention capture Perceptual tunneling increased congnitive distance if AR graphic is not overlaid from properly physical space to screen	There is need of faster visual processing of symbols, hence design should eb quick to understand FOV can limit scope of what to Augment. But it does not concern this thesis as we are focusing on whole windscreen as screen.
DAARIA: Driver Assistance by AR for Intelligent Automotive Paul George, Indira Thouvenin, Vincent Fremont...	The driver can perceive at any time the location of the dangers without leaving the eyes off the road.		DAARIA system
In Vehicle AR-HUD System to provide Driving Safety Information Hye Sun Park, Min Woo Park, Kwang Hee Won, Kyong Ho Kim...		If driving safety information does not match real environment, this can interrupt driver's concentration drive distraction is caused by oversaturation of information	

Part3

Literature part 3

Source	Advantages	Disadvantages	Solution
Assessing distraction potential of AR HUD for vehicle drivers Hyungil Kim, Joseph L. Gabbard	Helps keep eyes on the roads because AR information is shown in FOV Useful in foggy environment, night driving Virtual shadows improved participant's awareness of pedestriants while not affecting their awareness of other road elements	Frequently changing info cause inattentional blindness even within their central vision Drivers were able to detect speed limit signs or the lead vehicle ahead but less likely understood the meaning of the sign Highlighting object was considered as clutter by participants. Because it prevented perceiving fine details like heading, posture, orientation negative side effects of bounding boxes such as degraded driver's awareness of un-cued scene elements The bounding boxes may direct too much visual attention to pedestrians so that other critical objects are unattended	assess cognitive distraction in automobiles SAGAT- Situational awareness global assessment technique
Effect of Augmented Reality HUD system use on risk perception and psychological changes of drivers Yoonsook Hwang, Byoung-Jun Park, Kyong Ho Kim	selective visual attention- searching based on colour has been shown to be the fastest search method compared to size, brightness or geometric shape reducing number of collisions can improve an awareness of other road vehicles and pedestrians surrounding the driver can be used to increase the saliency of important elements in the driver's view and has potential to improve SA	Inexperienced drivers who have low levels of altruism and high levels of anxiety and anger tend to underestimate objective risk factors in traffic trying to follow digital route guidance in an unfamiliar place during heavy rush hour traffic can cause sensory overload and high anxiety which can compromise safety	
Allocation of visual attention while driving with simulated AR Robin Eyraud, Elisabeth Zibeth, Thierry Baccino	Highlighting cues helps attract attention thus helps detect target quickly AR enhances the visibility of elements that have high value to the driver helps optimise the visual attention helps detect roadside hazards such as pedestrians and warning signs	In vehicular systems multiply the number of sources demanding attention of drivers	Visual attention is guided by 4 factors: Salience, Effort, Expectancy and Value. Think if moving objects are to be cued or fixed objects to be cued? Should both be shown but in different colour or saliency? The eye movements are vert specific to goal in progress manoevre specific AR seems to lead to a more optimal allocation of visual attention than the control condition result show: AR only has an impact on the allocation of visual attention during decision making phase proves that using AR the allocation of attention is alrered