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THE DESIGN AND EVALUATION OF A NOVEL VEHICLE NAVIGATION SYSTEM

Valentine Nwakacha, BEng, MSc

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for the degree of Doctor of Philosophy

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Abstract

Vehicle Satellite Navigation Systems are commonplace but from a safety point of view, can be problematic. They are situated within small screens and often placed at an angle which is not in the driver's field of view. This promotes glances away from the road and reduces situational awareness for events which occur. Audio commands and visual maps which are used to instruct drivers typically require translation to situationally meaningful actions before execution in the real world. This increases the driver's workload and risk of distraction.

A virtual car head-up display concept which is novel to this thesis is introduced. The design was motivated by issues in the literature regarding workload and risk of distraction with current systems and was shaped using a field study. Also, as head-up displays are becoming common in new vehicles, the benefits they offer have been explored in the design of the virtual car head-up display. Navigation instructions would be embedded in a familiar object to the driver; a car image, to support driving practices (e.g. indicating, lane positioning and turning) which are absent in the abstract commands and visual maps employed by vehicle satellite navigation systems. The navigation instructions used by the virtual car head-up display are easy to understand and can reduce the processing times for the instructions. For example, rather than translate audio commands e.g. "after 200 yards turn left", the driver sees the virtual car indicate left 200 yards from the turn and sees it turn left on arrival at the turn. Also, rather than translate complex visual maps, the driver replicates the actions of the virtual car.

An initial prototype for the virtual car head-up display was designed after which usability evaluation was carried out in a driving simulator to refine the concept.

The first two studies were part of the design process and involved assessing the feasibility and conformity of the virtual car head-up display. It was found that the virtual car head-up display was an intelligible way to present the navigation instructions to drivers and that it was better to conform the virtual car to the external environment. The third study compared the prototype of the virtual car head-up display with the prototype of an arrow head-up display and vehicle satellite navigation system. It was found that the virtual car head-up display had the least workload and risk of distraction and was the easiest to use. A synthesis of the research work is provided which outlines the key contributions to research.

Acknowledgements

I start by thanking my immediate family members who sponsored my research and took out time to inspire me. I dedicate this thesis to them; my parents Ifediora Sr. and Obiageli and siblings Onyekachi, Chioma, Ifediora, Nonso, Chidinma and Chinenye for the love and support they showed me. I also thank my extended family members especially Ferdinand, Nonye, Lego, Chijioke and Chike for their support. Most especially, I thank Dr Chiedozie Udenka for all the advice and encouragement he gave me during my research.

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2D	2-Dimensional
3D	3-Dimensional
ANOVA	Analysis of Variance
AR	Augmented Reality
ASQ	After Scenario Questionnaire
CAD	Computer Aided Design
CD	Compact Disc
CDS	Crashworthiness Data System
CRT	Cathode Ray Tube
CUSI	Computer User Satisfaction Inventory
DALI	Driving Activity Load Index
EEG	Electroencephalography
ESPRIT	European Strategic Program on Research in Information Technology
F	F-value
FWD	Full Windshield Display
GPS	Global Positioning System

HCD	Human-Centred Design
HCI	Human Computer Interaction
HDD	Head-Down Display
HFRG	Human Factors Research Group
HMD	Head Mounted Display
HUD	Head-Up Display
ID	Identification
ISO	International Organization for Standardization
IVS	In-Vehicle System
LRT	Limited Resource Theory
MART	Malleable Attentional Resource Theory
MoD	Ministry of Defense
MR	Mixed Reality
MRT	Multiple Resource Theory
MUSiC	Metrics for Usability Standards in Computing
MVS	Making Virtual Solid
NASA-TLX	NASA Task Load Index
P	P-value (Probability)

PDE	Pre-Determined Event
PDT	Peripheral Detection Task/Test
RAD	Rapid Application Development
RP	Rapid Prototyping
STISIM	Systems Technology Incorporated Simulator
SUMI	Software Usability Measurement Inventory
SUS	System Usability Scale
T	T-value
UK	United Kingdom
USE	Usefulness Satisfaction and Ease of use
vNav	Visual Navigation
VR	Virtual Reality
VSNS	Vehicle Satellite Navigation System

Preface

The research which is presented in this thesis was conducted at the University of Nottingham between 2009 and 2014.

CHAPTER

1

INTRODUCTION

1.1 THE PROBLEM STATEMENT

Driving is an activity involving performance of concurrent tasks. One of these is the navigation task which has been identified as a primary task by Tasca (2005). Technological advancements witnessed in the field of navigation have led to the design of vehicle satellite navigation systems (VSNS) which are able to provide drivers with the required navigation support in unfamiliar navigation situations. Burnett and Parkes (1993) suggest that they provide pre-information about a turn so that drivers can stay on a route. A set of voice commands and visual maps are integrated in these systems as the instruction mechanisms for the driver during route guidance. The timely voice commands provide drivers with turn-by-turn instructions whilst the visual maps provide awareness of the route network. These enhance the driver's decision making and/or performance. For example, there are studies which have found that the voice commands reduce the time which is spent glancing towards the dashboard and the visual maps help drivers to anticipate upcoming turns (Kishi and Sugiura, 1993; Burnett and Parkes 1993; Lansdown, 1997). An account of how these systems support drivers in the real world during navigation is provided by Leshed et al. (2008).

However, they are located within small screens and on the dashboard as head-down displays (HDDs) (see Figure 1.1) which are not in the driver's field of view. Also, the voice commands and visual maps they use as their instruction mechanisms require translation into situationally meaningful actions e.g. for the voice commands "after 100 yards turn right" the driver has to cognitively process this instruction before executing it on the road. The driver would require spatial awareness to estimate 100 yards from the current position and spatial orientation to determine where the turn direction is. Also, for the visual maps the driver has to match the representation in the display with the real world which would promote additional glances away from the road scene. These can increase the driver's workload and risk of distracting the driver's attention from performing the primary tasks of driving.

Figure 1.1: Vehicle satellite navigation system on dashboard

Also, the way the instructions are provided do not resonate with the primary driving tasks and can interfere with performance in such tasks. For example, the primary driving tasks do not include listening to voice commands or looking at visual maps in a display. When drivers have to perform this tasks then they can be prone to shifting their attention from performing the primary driving tasks.

1.2 THE RESEARCH MOTIVATION

It could be useful to address these issues which have been identified with vehicle satellite navigation systems in an alternative navigation system thereby adding to the existing knowledge for the design of navigation systems in vehicles. The system would abnegate the work of translation and support the driver in focusing attention on the road scene. Also, the system would align the navigation instructions with the primary driving tasks. Wilson (2011) highlights that design should aim to support users effectively and intuitively. Hence, achieving these aims could make it possible for such a system to reduce the additional workload of the driver and the risk of the driver's attention being distracted from performing the primary driving tasks. This research is conducted in line with these ambitions. A review of the literature was done and a field study was conducted to study the context of use in the real world and obtain design requirements. These helped shape the design of a new navigation interface which is known as the virtual car head-up display.

The virtual car head-up display concept is new and owned by the author and supervisors of this thesis. It is a novel concept which proposes that the navigation instructions would be embedded in a virtual image of a car, an object which is familiar to drivers and which supports various driving practices that are not employed by vehicle satellite navigation systems e.g. staying in lanes, indicating and turning. The virtual car head-up display uses conformal scene augmentation where the virtual car would be collimated in the real world so that it appears at a focal depth in the driver's field of view through the transparent medium of the windshield. This can allow the navigation instructions to be situated at focal points in the real world. Also, this would relocate the driver's attention from within the vehicle to the outside world whilst driving, thereby, can reduce the visual shift of attention when perceiving the navigation instructions.

Also, integrating the navigation instructions which are required by the driver in the virtual car is aimed at reducing the work of translation for the navigation instructions. This is done so that the drivers would be able to draw on their competence in real world navigation because they are familiar with the instruction mechanisms used (e.g. following other vehicles, indicating, turning, staying in lanes etc.). Hence, instead of processing the abstract voice commands e.g. “after 100 yards turn right”, the driver sees the virtual car indicate right 100 yards away from the junction and sees the virtual car turn right at the junction. Also, instead of processing a visual map, the driver sees the virtual car provide the information which is required to follow the route and replicates the actions displayed. A comparison of the virtual car head-up display and vehicle satellite navigation system is shown in Figures 1.2 and 1.3.

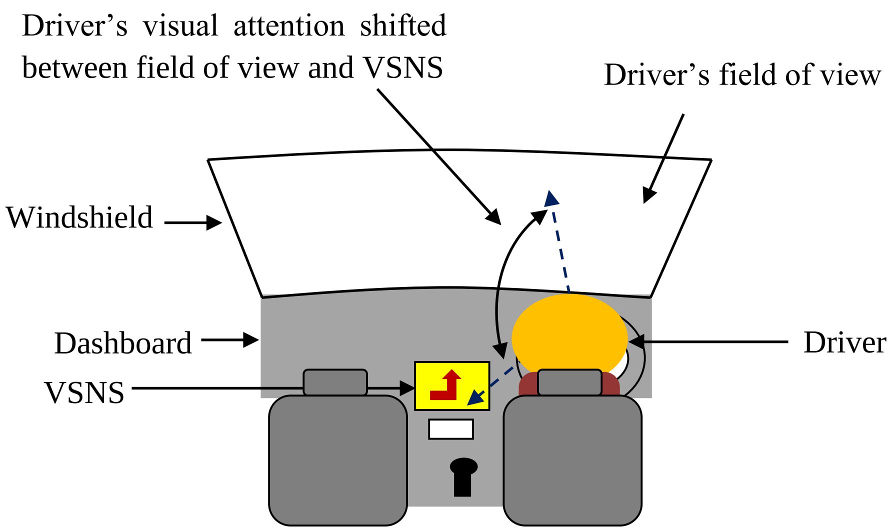

Figure 1.2: Driver using vehicle satellite navigation system

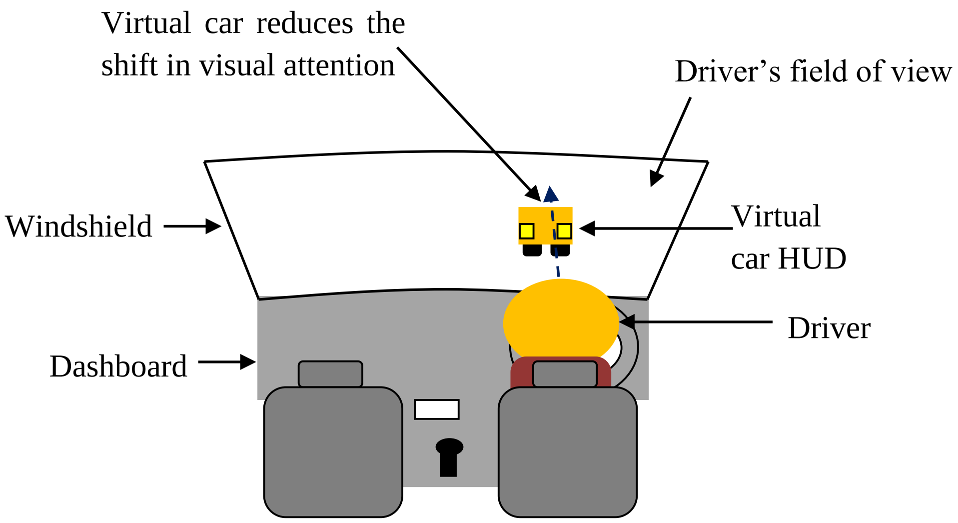

Figure 1.3: Driver using virtual car head-up display

The virtual car is situated on the windshield as a head-up display and this presentation approach has been highlighted in the literature as an alternative way to provide drivers with information which would not be situated on the dashboard. According to Tönnis et al. (2005), a head-up display (HUD) takes icons and text that are usually found on the dashboard of a car and displays them in the windshield, helping drivers to keep their eyes on the road. Burnett and

Donkor (2012) highlighted that a head-up display would allow a driver to take in secondary information whilst attending to the forward road thereby reducing diversion of attention from the road scene. Several examples of head-up displays are shown in Figures 1.4[1], 1.5[2], 1.6[3] and 1.7[4].

Figure 1.4: BMW M6 head-up display

Figure 1.5: MVS virtual cable navigation system

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[1] http://www.businessinsider.com/every-car-should-have-a-head-up-display-2013-6
[2] http://www.mvs.net/
[3] http://www.youtube.com/watch?v=YjCDZ3plT3k
[4] http://wordlesstech.com/2012/05/11/cyber-navi-augmented-reality-hud-video/

Figure 1.6: Garmin head-up display

Figure 1.7: Cyber Navi system

It has been found that the use of head-up displays resulted in better decision making and/or performances when compared with head-down displays (HDDs) in various driving studies (Liu and Wen, 2004; McCann and Foyle, 1994; Yeh and Wickens, 2000; Charissis et al., 2008; Gish & Staplin, 1995). For example, Liu and Wen (2004) suggested that the head-up display had a faster response time and speed control was more consistent when compared with a head-down display. Also, Charissis et al. (2008) suggested that under low visibility conditions the head-up display reduced the number of collisions and improved subjects’ maintenance of following distance when compared with a head-down display.

Despite these benefits of head-up displays, several authors in the literature have suggested that they can also cause a number of problems to drivers e.g. misaccommodation, attention capture and visual clutter (Ward and Parkes, 1994; Crawford and Neal, 2006). It is possible that these can increase the driver’s workload and the risk of distracting the driver’s attention from the road scene. As a result, the virtual car head-up display design takes these factors into consideration to avoid reintroducing them in its design. For example, the virtual car can be projected on the windshield using intelligent devices so that it would be conformed to the road scene and the navigation instructions can be well tailored for the driver. This could reduce the misaccommodation problem which according to Ward and Parkes (1994) occurs when a driver is not able to visually accommodate information in the near domain which is pulling attention inwards and reducing attention on information in the far domain. Reducing the misaccommodation problem could allow the driver to visualize both the near and far domain simultaneously. The virtual car also integrates an inactive state to reduce the risk of attention capture where the driver’s attention could be drawn to an object which is constantly active on the windshield. This inactive state would allow the driver to focus less attention on the virtual car and instead on the events in the road scene.

Furthermore, with a number of driving information provided on the windshield, there is the risk of causing visual clutter and possible masking of critical information in the road scene with a head-up display. Therefore, the virtual car head-up display design is simple but very effective in providing navigation information so that there is no need for unnecessary icons and texts to be on the windshield. Hence, the driver's field of view is free from visual clutter and there is proper view of the road scene. It is anticipated that reducing these effects would make the virtual car head-up display a navigation interface which is easy to use and one which has positive safety impacts on the driving tasks.

1.3 THE RESEARCH AIM AND OBJECTIVES

The aim of the research was to:

- Introduce, build and evaluate a new alternative navigation interface to those existing which would be associated with less workload demands and risk of distraction for drivers.

To accomplish this, the objectives included to:

- Investigate from existing literature how increase in workload and the risk of distracting the driver's attention from the road scene are evident in existing navigation systems.
- Configure design specifications for the virtual head-up display in a test environment.
- Conduct usability evaluations to empirically assess the viability of the design concept and the best way to tailor the navigation instructions. Furthermore, a comparison of the virtual car head-up display prototype with prototypes of existing navigation systems would be made to assess behaviour and performance measures with each of the navigation systems.

- Provide an overall discussion on the implications concerning the virtual car head-up display for the design of navigation systems in vehicles.

1.4 THE STRUCTURE OF THE THESIS

The structure of the thesis is shown in Figure 1.8. The structure of the thesis outlines the key questions which drove the research investigation and outcomes. The work which was done in each chapter is outlined and the chapter number is shown in the brown box.

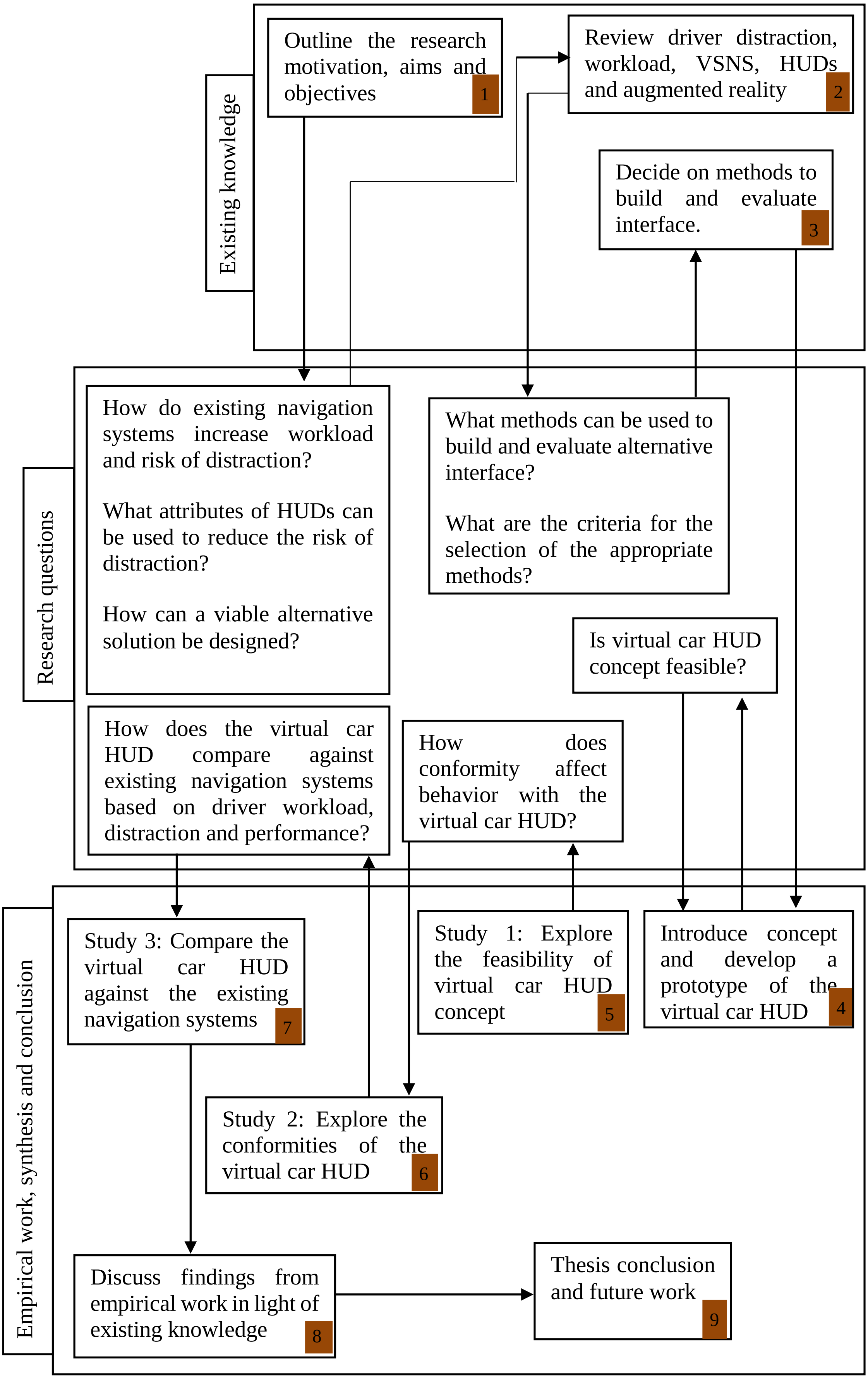

Figure 1.8: The structure of the thesis

1.5 SUMMARY OF KEY RESEARCH OUTCOMES

The usability evaluations in this research showed that our new virtual car head-up display is an intelligible way to present navigation instructions to drivers as drivers were able to replicate the navigation instructions provided by the virtual car during navigation. The conformity study showed that conforming the virtual car to the external environment is better for the virtual car to avoid the issue of misaccommodation. Also, the feasibility and conformity studies helped shape the eventual design of the virtual car head-up display during the development process. Finally, when compared with prototypes of existing navigation systems, the virtual car head-up display was associated with the least amount of additional workload and risk of distracting the driver's attention from the road scene. It was also rated as the easiest navigation interface to use. These show that the virtual car head-up display has positive safety implications while driving.

Finally, the virtual car head-up display has a number of implications for the design of future navigation systems in vehicles. For example, it can be used as a navigation tool which aligns the navigation instructions provided with the primary driving tasks to reduce the interference on performance of such tasks. The drivers can spend less time and attention on translating the navigation instructions from the virtual car and instead optimally perform the primary driving tasks. It can also be used as a tool for training new drivers where their learning is enhanced by the use of this visual aid which dictates actions to be carried out at specific locations in the real world. The findings from the studies along with the design concept and implications of the virtual car head-up display are key contributions to the research area.

1.6 THESIS PAPERS

1. Nwakacha V. I. (2011): Mobile and location-based computing in cars. Doctoral Colloquium: The 2011 European Computer-Supported Cooperative Work conference, Aarhus, Denmark. pp 1 – 4.

2. Nwakacha V. I., Crabtree A. and Burnett G. E. (2013): Evaluating distraction and disengagement of attention from the road. In Proceedings of the 15th International conference on Human-Computer Interaction, Las Vegas, Nevada, USA. pp 287 – 296.

CHAPTER

2

LITERATURE REVIEW

2.1 INTRODUCTION

The previous chapter set the scene by summarizing the issues with existing navigation systems. There was a preamble to the nature of workload increase and risk of distracting the driver’s attention with vehicle satellite navigation systems. It was pointed out that there is the work of translation of the instructions to situationally meaningful actions which occurs when using vehicle satellite navigation systems because of the instruction sets they employ. The issues with head-up displays were very briefly touched upon to further provide a sense of the issues to deal with in the design of an alternative interface. The focus of this chapter is to elaborate on these issues in more detail by reviewing current literature to grasp a better understanding of the factors which surround the issues at stake. The review highlights the impact which vehicle satellite navigation systems can have on a driver’s workload and how this affects the risk of distraction. Furthermore, it explores the design of head-up displays to identify different aspects which have been identified as beneficial and can suit the research aims. The concept of augmented reality is examined to identify the benefits it presents for the design of future systems in vehicles. Finally, there is a discussion on how the issues which have been highlighted can be addressed in a potential design concept.

2.2 VEHICLE SATELLITE NAVIGATION SYSTEMS

Vehicle Satellite Navigation Systems (VSNS) have become commonly used devices in today’s driving. According to a 2007 Gallup survey for the European Union, it was found that up to 35% of its citizens which accounts for approximately 159 million people currently use or intend to purchase a satellite navigation system (Keith and Burnett, 2008). It is possible that this figure would have increased since then. Vehicle satellite navigation systems are electronic devices which are fitted on the dashboard during manufacture or brought into the vehicle to issue route guidance instructions in unfamiliar situations. Pauzie (2008) indicated that "they provide navigation and route guidance which are designed to assist drivers at the strategic level of driving by supporting the navigation process. They also support driving at an operational level by supporting drivers to anticipate upcoming manoeuvres". Also, Burnett (2000) highlighted that the vehicle satellite navigation systems aim to support drivers when travelling within unfamiliar areas, leading to a more efficient use of the road network, reduced demands and increased confidence compared to current methods. Vehicle satellite navigation systems use Global Positioning System (GPS) signals to track the driver's vehicle on the route thereby enhances the driver's navigation decision making and/or performance and increases efficiency when making journeys. A typical vehicle satellite navigation system is shown in Figure 2.1.

Figure 2.1: A dashboard vehicle satellite navigation system

There are two main tasks which are involved in the use of vehicle satellite navigation systems. These are destination entry and route guidance tasks.

Destination entry task

The first task involved in using vehicle satellite navigation systems is destination entry. Before the start of a journey, the system prompts the driver for a destination address. The driver keys the address into the system which then displays one or more routes on its visual display based on factors such as the shortest route, fastest route, least traffic etc. to reach the destination. The driver accepts one of the displayed routes and several turn-by-turn instructions are then issued once the driver sets off. Young et al. (2003) highlighted that one of the major concerns which relate to the use of vehicle satellite navigation systems is that of the destination entry task where the task duration is often affected by the complexity of the information entry process. Farber et al. (2000) stated that depending on the type of system and how information is entered the process can take drivers up to 9 minutes to complete.

There is also the issue surrounding whether the driver should be allowed to enter information whilst the vehicle is in motion. Young et al. (2003) indicated that some vehicle satellite navigation systems allow drivers to enter information into the system only when the vehicle is stationary while several others can allow information entry when the vehicle is moving. Entering information whilst controlling a moving vehicle can have an impact on the task execution of at least one of the tasks because the driver can only focus on one of the tasks at a time.

The destination entry task can be performed in several ways. Farber et al. (2000) and Tijerina et al. (2000) highlighted the following:

- Selecting the required destination from a scrolling list of cities, suburbs and street names

- Manually typing in the street number, name and suburb of the destination letter by letter
- Voice input

Young et al. (2003) pointed out that the first two methods are the longest and most physically and cognitively demanding. However, they indicated that they are the most commonly used methods by drivers. Selecting the destination from an already available list may be perceived as an easy task to perform. However, the driver has to scroll up or down to search for the destination on the list and this may take time to complete especially if the list of addresses is long. Manually keying the destination address letter by letter is physically and/or cognitively demanding because the driver has to ensure that the address details are entered correctly for the navigation system to find a match and select an appropriate route. Predictive typing is now available in some vehicle satellite navigation systems to speed up the process[5]. When a road name, postcode or address is typed, some suggestions would be offered while typing from which a match could be found.

The voice input is perhaps less demanding than the other two methods according to Young et al. (2003). However, it is possible that there may be issues of matching the spoken destination addresses with the information which is contained in the system database. Also, factors which include noise, accent and tone of the driver may affect the use of the voice input method. The destination entry task is a fundamental aspect of using vehicle navigation systems but the risk which is involved especially if the driver is allowed to enter information into

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[5] http://www.goodhousekeeping.co.uk/tried-tested/tomtom-go-6000-satnav-2013

the system when the vehicle is in motion is one which requires serious consideration.

Route guidance

The next task which is involved in using vehicle satellite navigation systems is route guidance and this task commences when the destination entry task has been completed and the driver sets off. Here, the driver would be guided along the route using a specified set of actions. When providing the driver with route guidance information, Farber et al. (2000) highlighted that vehicle satellite navigation systems use electronic visual displays or spoken commands or both. Also, Srinivasan and Jovanis (1997) and Tijerina et al. (2000) highlight that the visual displays present information via route maps or turn-by-turn displays. The route map is typically a 2D aerial representation of the route followed (some modern vehicle satellite navigation systems integrate 3D maps, e.g. see navman S30, mio C620 and navigon 8410) which allows the driver to anticipate turns along the route. This helps to enhance the driver's awareness of the route network. The turn-by-turn displays use an arrow to indicate the direction of the next turn. Also, the spoken commands instruct the drivers on the necessary actions to perform to remain on the route. They include instructions such as 'turn left', 'turn right', 'after 200 yards take the first exit at the roundabout', 'you have reached your destination' etc. Sanders and McCormick (1993) suggest that these are acceptable ways which the instructions can be presented to the drivers.

It is believed that integrating voice guidance messages is critical for safe and efficient vehicle satellite navigation systems (Ross et al., 1995; Green et al., 1995). The voice commands can reduce the need for the driver to look away from the road because when the driver looks at the dashboard, then it is not possible to look at the road. Studies have found that the addition of voice messages reduces the time spent glancing towards an in-vehicle system (IVS) (Kishi & Sugiura, 1993; Burnett & Parkes 1993; Lansdown, 1997, etc.) which helps to reduce any negative effect on the driver's visual awareness of events on the road.

2.2.1 ISSUES OF CONCERN WITH VEHICLE SATELLITE NAVIGATION SYSTEMS

The main problems with vehicle satellite navigation systems are that they are small and typically located on the dashboard. The small screens can increase the difficulty of information capture as the driver may be forced to look severally at the display in order to completely capture the required information. This can increase the risk of distracting the driver's attention from the road when using these navigation systems (Dingus et al., 1995; Schraggen, 1991; Tijerina et al., 2000). Also, displaying information on the dashboard can promote additional glances away from the road scene and can negatively affect a driver's situational awareness, decision making and/or performance in the primary tasks. There are several ways through which the use of vehicle satellite navigation systems can affect drivers and include the following:

- **Visually**: Drivers can divert their visual attention away from the road by looking at the visual display which is not in their field of view. These systems are typically located on the dashboard which means that to look at the visual display the driver would have to look away from the road. Also, the route maps may be complex which would promote additional glances towards the visual display thereby increasing the amount of time the driver spends looking away from the road. It was suggested by

Wierwille (1993) that drivers would rather increase the number of glances at a system for extended periods of time than the glance duration.

- **Cognitively**: Drivers can divert their cognitive attention to process the voice commands or route maps to make a decision. The driver may need to store the information from the system in memory before executing them in the real world. This could result in extra demand for attentional resources to retain and process the information to be delivered at the right time.
- **Auditorily**: Drivers would need to listen to the spoken commands which are issued during the route guidance task. The spoken commands can disrupt the driver's attention during the performance of the primary tasks because the driver may need the information provided by the system at decision points along the route.
- **Physically**: Drivers can be physically distracted when they decide to take their hands off the steering wheel in order to key information into the system.

It is possible that the driver may encounter more than one of these types of distraction at any particular point in time. For example, there can be auditory distraction (listening to audio commands) and visual distraction (looking at a visual map) at the same time.

Apart from distracting the driver's attention from the road, there is also the work of translation required from the driver because the voice commands from the vehicle satellite navigation system need to be translated to situationally meaningful driving practices before they can be executed. The reason is because the instructions are usually abstract in nature e.g. “after 100 yards turn left”. The driver would have to deal with several problems when translating this instruction. For example, a spatial awareness and orientation of the outside environment might be required to know where 100 yards is from the current location in order to identify the location and direction of the turn. The driver may fail to perform some of the primary functions which are involved in making a turn e.g. indicating or lane positioning, when doing this translation work and as a result may fail to inform surrounding drivers of their intentions on the road. This can create an unsafe driving environment for the other drivers on the road.

In addition to this translation work, Burnett (2000) discussed the implications of wrong timing of the voice commands. He highlighted that for early-timed messages, there would be demands on the driver’s memory which may promote additional glances to a complementary display and/or use of a repeat function. This may arise, for example, if the driver forgets some parts of an instruction which has been provided already. Burnett (2000) also pointed out that for messages which are presented too late there is the likelihood that there may be undesirable driving behaviors with implications for overall safety e.g. late/non-existent indicating, sudden lane changes and sharp braking etc. The timing of the messages can cause significant issues for the driver and even complicate the translation work because when the information that is required to make the decisions is not available at the right time then there can be more work put in to anticipate or correct the outcomes of the situation. For example, well-timed messages would allow the driver to anticipate, prepare and execute a turn instruction properly. The driver can enter the correct lane, watch for oncoming traffic and indicate the direction of turn when it is safe to do so. Poorly-timed messages can cause the driver to make late or correct wrong decisions which means that the driver does more work eventually.

The major concerns which have been stipulated for vehicle satellite navigation systems is their impact on the driver’s workload and risk of distracting the driver’s attention from the forward road. Therefore, it is important to understand these concepts in order to further identify the nature of the problem which these systems cause when drivers engage with them during navigation.

2.3 UNDERSTANDING WORKLOAD

Workload is a term which is suggested to have been derived from cognitive and physiological theories in psychology. There have been many definitions for the term, for example, Wickens and Hollands (2000) stated that workload is “the amount of information processing resources (and limits thereof) used for task performance”. Son and Park (2011) defined workload as “the amount of resources that is required to perform a particular task”. When performing tasks, it is important that optimal workload is achieved to avoid more or less demands on the individual. According to Hart (1991), this optimal workload is defined as "a situation in which the operator feels comfortable, can manage task demands intelligently and maintain good performance". This optimal workload should be the focus of design when providing systems which would be used by drivers in a demanding task as driving.

One of the key factors regarding workload is highlighted by Rouse et al. (1993) where they indicated that workload is not only task-specific but person-specific. The implication in this statement is that even though the task itself can have an effect on the level of workload of an individual, the state of the individual also matters because different individuals would deal with the same level of workload in different ways. For example, drivers can monitor the road scene in different ways whilst tuning the radio. Also, the personal attributes of individuals would make certain issues to affect certain people more than others e.g. drivers who are visually impaired are more likely to struggle with viewing objects at certain distances when compared with others that are not. In addition to this, Tasca (2005) highlighted that based on the limitations of humans to process information one at a time, different individuals cope with the same level of workload in different ways. This can be based on which aspects they assign priority and how quickly they deal with the information. This would enable them to distribute their attention resources appropriately to the other tasks.

Workload changes can occur at different times when performing a task, e.g. based on additional tasks initiated by the individual, the task itself, environmental factors or a combination of these. In driving, there can be changes in workload when drivers engage in other tasks which are not in line with the primary tasks. For example, high workload demands (overload) can result when the driver attends to a primary task e.g. manoeuvreing the vehicle in a high volume of traffic whilst also performing a secondary task e.g. conversing with a passenger. Also, it is possible that there can be low workload demands (underload) e.g. in a boring journey, when the driver is faced with performing little to no tasks whilst driving. When these workload changes occur, it is possible that the driver may struggle to cope if there are similar attention resources required to perform both sets of tasks. This can lead to resource sharing to ensure that the driver can cope with the additional demand from both tasks. Meister (1976) outlined a hypothetical relationship that exists between the amount of workload of an individual and their performance. This is shown in figure 2.2.

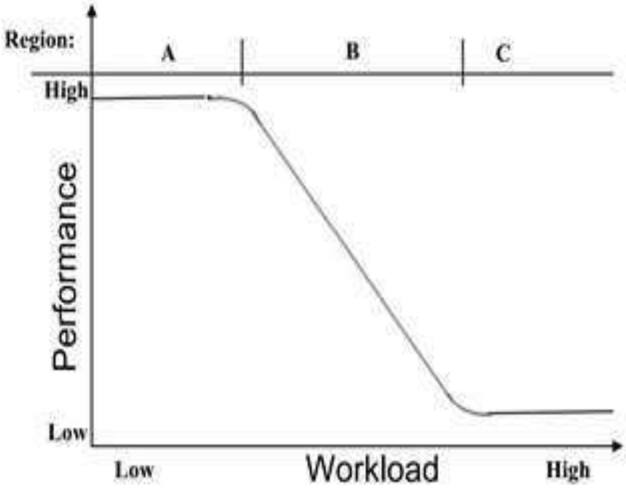

Figure 2.2: Hypothetical relationship between workload and performance (based on Meister, 1976).

The region A is used to indicate a region of low workload such that even when the workload is increased, performance can still be unaffected. Region B is the region where workload increase begins to cause a steady decrease in performance. Region C is the region where when workload exceeds an upper limit then driving performance will be at its minimum and does not degrade further. Even though an increase in workload is likely to affect a human's performance and lead to degradation, the figure indicates that this may not be the case, until the threshold value is reached.

The next few sections examine the different types of workload and they aim to provide an understanding of the different means through which the driver's workload can be affected. In the literature, three predominant types of workload have been identified. These are the visual, auditory and cognitive workload.

2.3.1 VISUAL WORKLOAD

The driving task is a highly visual task by nature which suggests that there would likely be a high demand for visual attention. Sivak (1996) highlights that the visual workload is the most predominant aspect of the driver's workload. With technological advancements such as vehicle navigation systems which introduce additional displays for the driver to monitor while driving, the driving task has become an even more complex visual task to manage. Gelau et al. (2004) highlighted the increasing concern in research due to this increasing proliferation of systems into vehicles where these systems can increase the driver's workload and risk of distracting the driver's attention from the road. The driver's visual workload can be affected by the number and complexity of information taken in while driving. Engström et al. (2005) highlighted that when performing a visually demanding secondary task (e.g. operating the radio) concurrently with the primary task there can be time sharing of visual resources to cope with the demands of performing both sets of tasks simultaneously. This time sharing can be tied to the fact that humans are only able to process information one at a time as suggested by Tasca (2005) and performance in one or more of the tasks can be affected due to the high workload demand experienced.

Visual workload measures can be categorized into two; direct and indirect measures. The direct measures include those which record and analyze the visual behaviors of drivers. An example of a direct measure of visual workload is eye tracking. Eye tracking using specialized equipment allows the exact position of the eyes to be monitored so that it is easy to identify which objects are fixated upon. The indirect measures include those which infer visual workload through other metrics. Lansdown (2001) highlighted that all measures for visual workload are obtained from the same fundamental visual behavior (i.e. glances and transition between glances) which are composed of fixations and saccades. Glancing is a feature of visual perception where the eyes move towards an area of interest to capture information. Wierwille (1993) defined a glance as “the movement of the eyes towards a certain area of interest for a period of time and then subsequently moving it to another area of interest”. Rockwell (1988) defined it as “a series of fixations in the same target area”. Engström et al. (2005) also indicated that the visual demand which is imposed on drivers by secondary tasks can be directly quantified by means of two main eye movement measures: glance frequency and duration.

The glance frequency refers to the number of glances made towards a specific target area over a given period of time. Wierwille (1993) highlighted that the glance frequency is a measure which reflects the difficulty of information uptake when performing a specific task. This means that tasks with higher difficulty would likely require more glances towards an area or object of interest (e.g. a visual display). The glance duration refers to the amount of time which the driver takes to move visual attention from one point of interest to another e.g. a dashboard display, before moving to another point of interest. The glance duration is usually factored in to obtain the eyes-off-the-road time and the higher this value is the more unsafe is the situation for the driver. Kircher (2007) highlighted that “the notion that glances away from the road which last for more than two seconds are extraordinarily long and hazardous is a recurring statement in the literature”. Wierwille (1993) suggested that drivers would rather increase the number of glances at a system for extended periods of time than the glance duration. This would be to compensate for the loss of information captured within short periods of time and gain more awareness of occurrences in both areas i.e. system and road.

Apart from the frequency and duration of glances, other measures exist for measuring the visual demand associated with objects. They include total glance duration, percentage glance duration and fixation probability. Hancock and Desmond (2001) defined the total glance duration as “the cumulative time which is spent looking at a given target location for the duration of a given task”. This can be used to calculate the total eyes-off-the-road time by adding the total fixation durations. The maximum glance duration is “the longest period of time which is spent on a target location without glancing away from it” (Basacik and Stevens, 2008). The percentage glance duration is “the percentage time which drivers fix their gaze on a target location in relation to other target locations for the duration of a task” (Gawron, 2001). This can be used to determine which locations inside or outside the vehicle have the highest tendencies to draw the driver’s attention. The fixation probability is “the likelihood that a given location will be fixated upon during task performance” (Hancock and Desmond, 2001). This can be used to identify if a target location would cause drivers to divert their attention away from the road and towards the target location.

In the driving task, increased visual workload can cause drivers to take their eyes off the road at times when they interact with visually demanding displays which are not in their field of view e.g. dashboard-mounted vehicle navigation systems. Godthelp et al. (1984) suggested that when there is visual attention diverted from the road (e.g. by a secondary task or by visual occlusion), the driver cannot give any tracking response and this results in periods with fixed steering wheel angle.

This would result in heading errors which cause lane weaving and in some cases lane exits. The length of time which this lasts is often affected by the complexity of the visual display such that simple displays can result in less glance frequencies and durations when compared with more complex displays.

In the literature there are studies which have shown that a relationship exists between a driver's visual workload and distraction-related behavior. For example, Dingus et al. (1989) showed that glance durations were subject to variations in visual workload but remained within a relatively small range. Also, glance frequency appeared more representative of increases in task complexity. Greenberg et al. (2003) found a strong link between increased visual workload and reduced lane keeping and peripheral object detection reduction. They stated that their participants deviated within the lane under high visual workload and that visual loading tasks (e.g. phone dialing) led to reduced detection of critical traffic events. Antin et al. (1990) and Curry et al. (1975) showed that high visual workload resulted in speed reduction. They considered this a compensatory effect where drivers reduced the primary task workload to maintain their driving performance at an acceptable level. Olsson (2000) highlighted that visual secondary tasks impeded signal/event detection performance i.e. significant effects of visual workload on peripheral detection task performance was noticed. The findings from distraction-related studies suggest that visual workload increase or decrease can have an effect on the driver's visual behavior.

Recently, Intel did a demonstration in a Research @Intel event in San Francisco for their new technology which could study the visual workload of the driver using eye-tracking. The technology was used to determine where the driver was looking whilst driving[6]. They used cameras to capture the driver's face and eyes. The system would obtain data in real time based on where the driver was looking using the reflection and geometry of the camera and light emitters. In the monitoring display, there was a green line which indicated the driver's line of focus in the forward view. There was no data collected during the demonstration but this type of technology could be useful to accurately highlight the exact points where the driver focuses their attention whilst driving.

The International Organization for Standardization (ISO) put forward a standard which is being used to give guidance on the terms and measurements relating to the collection and analysis of driver visual behavior data (ISO, 2002, pg iv). Some of the common terms are outlined in Table 2.1. The standard provides a reference on how certain terms should be used and also stresses the importance of defining the investigated variables.

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[6] http://www.youtube.com/watch?feature=player_detailpage&v=YEhxEJOzpcY

Table 2.1: Selected terms and definitions of glance behavior during driving from the ISO standard 15007-1:2002 (p. 2f.) with comments.

Term	Definition	Comment
Dwell time	Sum of consecutive individual fixations and saccade times to a target in a single glance	A glance to a target can thus consist of several fixations and saccades
Glance duration	Time from the moment at which the direction of gaze moves towards a target (e.g. the interior mirror) to the moment it moves away from it	The transition to a target and the dwell time on the target are included in the glance duration but not the transition away from the target
Glance frequency	Number of glances to a target within a pre-defined time period or during a pre-defined task where each glance is separated by at least one glance to a different target	
Target	Pre-determined area within the visual scene e.g. a rear-view mirror	
Transition	Change in eye fixation location from one defined target location to a different location	
Transition time	Duration between the end of the last fixation on a target and the start of the first fixation on another target	

In summary, visual workload is a critical aspect associated with driving due to the very complex nature of the road scene. Increased visual workload due to performance of secondary tasks can cause shifts in the driver's attention from the primary tasks and affect their performance in those tasks. It is therefore important that for safety reasons the visual workload implicated in the use of a navigation system does not affect optimal performance of the primary tasks.

2.3.2 AUDITORY WORKLOAD

Auditory workload involves the driver listening to speech, audio or sound instructions which may be related to the driving task. These can include listening to words which are spoken over a phone conversation or with a vehicle passenger, music from radio or entertainment system or external noise. Auditory information is one of the ways through which people perceive information from their surrounding environment. Baldwin (2012) indicated that auditory systems make use of sounds, whether verbal or non-verbal or both to provide information to a human operator. Any increase in the auditory workload of a driver can affect how attention is allocated to the primary tasks as the driver may have to share attention resources to handle the additional workload and perform the driving tasks at an acceptable level e.g. when conversing on the phone, the driver may occasionally move attention away from detecting objects in the forward road scene in order to process messages and provide adequate responses.

Certain aspects of literature have suggested that there is not much significance to the auditory workload. Zhang et al. (2008) considered auditory perception to not be a major requirement when the driving task is performed because when there is an activity which involves audition, the driver is mostly affected cognitively. It is important that the impact of the auditory workload is not understated by any means because the implication of the argument raised by Zhang et al. (2008) is that the more the auditory workload then the more the impact there is likely to be on the driver’s cognitive resources. For example, long and complex audio commands can affect the driver’s processing of the information. The driver may require a long time to assimilate, retain and translate the instruction into meaningful actions and this can affect the attention to other tasks. Also, by having to listen to the audio information and use them to achieve specific goals the workload of the driver is increased along with the risk of distraction.

Another factor which is concerned with delivering auditory information other than the complexity is the timing of the messages. If the information is poorly timed, then there can be difficulty for the driver when using the information. Burnett (2000) discusses the impact of timing audio messages for the driver and indicated that audio messages which instruct drivers on actions to take can often be poorly-timed in one of two ways; early-timed or late-timed messages. Early-timed messages can pose challenges for drivers to retain and recall the information at the right time. If the information is presented too early to the driver then it is possible that bits of the information can be forgotten which can lead to errors. Also, if the information is presented too late, then it is possible that the driver can be caught unaware to perform a task. This can lead to extreme situations such as wrong lane positioning, sudden braking and missed turns.

Even though listening to auditory information can increase the driver’s workload, evidence in literature exists (e.g. Dingus et al., 1995; Srinivasan and Jovanis, 1997) which suggests that providing audio commands with visual maps can lead to better performance when compared to providing without the audio commands. The prompts are useful for notifying drivers on when actions should be performed and the above studies showed that better navigation performances were obtained when the audio commands were used along with the instructions. An important consideration is that audio commands should be provided in such a way that reduces the translation work which the drivers would require for performing the primary tasks. The information should be in such a way that is easy to understand and execute so that there is less work put in by the driver when executing the instruction. It is possible that this can help to address the issue of workload and risk of distracting the driver’s attention from the road scene with audio systems.

2.3.3 COGNITIVE WORKLOAD

Cognition can be considered a major part of the human processing unit and cognitive workload can be regarded as a vital aspect to consider to understand in driving performance. Several authors have studied cognitive workload and provided definitions for the term. For example, Wickens and Hollands, (2000) defined it as “the relationship between a human’s cognitive resource supply and the task’s demand”. De Waard (1996) defined it as ‘the amount of information processing resources used per time unit for task performance’. Humans make use of cognitive resources continuously because of consumption of information from our external environment. Given the highly complex nature of the driving task, it is expected that drivers would be continuously using cognitive resources to process information and make decisions at very quick speeds. Hence, in relation to the driving task, Patten (2007) highlighted that “the driver’s cognitive workload is related to human information processing capacity and the use and allocation of the driver’s attention”.

An important factor which affects cognitive workload is task complexity. Edquist (2008) defines task complexity as "the number of different resource types demanded". Also, that the task difficulty is how much of a resource (or resources) is demanded. Humans are usually limited in their ability to process every stimulus they receive because of the very large amount of information which is consumed and the limited amount of resources which are available to process such information. As a result, the literature suggests that there is a selective pattern of behavior where the most important aspects are considered whilst the rest are ignored. This can help in optimizing performance in the selected tasks. However, this process can often be made complicated when humans process complex tasks over simpler ones. Increasing the complexity of a task would likely mean that more there are attention resources needed by the driver to perform the task. For example, this can happen when there is increase in the complexity of the visual and auditory information taken in. The driver may limit the number of information sources which are engaged with in order to reduce cognitive workload. However, Cooper and Zheng (2002) indicated that this may lead to impaired driving if the drivers make the wrong decision. The drivers may miss out on critical information and so may affect their performance in the decision making process.

Cognitive processing activities require memory resources and when dealing with information processing, Baddeley (1986) indicated that working memory is often utilized. Baddeley defined this working memory as a "system for the temporary holding and manipulation of information during performance of a range of cognitive tasks". Wickens & Hollands (2000) indicated that cognitive processing (e.g. reasoning, planning, image transformation etc.) which is performed while driving involves the use of working memory which is a vulnerable, temporary store for relevant information. The working memory is useful because individuals may not be able to deal with different information at the same time and this working memory can allow different tasks to be dealt with and the space freed up for other tasks which require memory resources. Baddeley (1986) goes on to outline two categories of working memory. These are general and specific working memory. The general working memory was defined as “a temporary storage for processing of information when dealing with a range of cognitive tasks”. The general working memory can be used to process information quickly and the space released for other tasks that require the same resources. They also defined specific working memory as “a precise model of the structures and processes which are involved in carrying out general working memory tasks”.

Cognitive workload can be measured in several ways: via physiological measures such as pupil dilation, heart rate variability, EEG signals; via secondary task performance which is assumed to worsen as the primary task workload increases; or by asking the person under load, i.e. subjective ratings (Kantowitz, 1987). There are several studies which have looked at how a driver’s cognitive workload can be affected. For example, Olsson (2000) reported degrading effects in the peripheral detection task in purely cognitive loading tasks when drivers were asked to detect a peripheral object while driving. Greenberg et al. (2003) reported reduced detection of critical events in simulators due to cognitive tasks. Recarte and Nunes (2003) found reduced event detection as well as a concentration of gaze towards the road center during certain cognitively loading tasks, such as word production and complex conversation. Also, Horrey and Wickens (2004) found that the drivers' reaction times were significantly increased when conversing on the phone and driving.

Recently, Intel did some research into distracted driving to study what the driver thinks about whilst driving so that they can alert the driver of any mental warning signs before the driver gets behind the wheel[7]. They did a demonstration in a Research @Intel event in San Francisco which made use of a functional near-infrared spectrometer headband to gauge the metabolic activity and cognitive workload of the brain under different scenarios (ranging from peaceful drive to high-speed chase). The headband was reported to use light to monitor brain blood flow as a proxy for workload stress which a user may experience when performing an increasingly difficult task. The band uses laser diodes to send near-infrared light through the forehead at a relatively shallow depth after which it can judge how intense the driver's workload is (or is not). They made the driver answer a few questions along with some mathematical problems while driving to complicate the task. They found that the driver's brain was highly active during the more challenging scenarios and less active in the easier scenarios. This meant that by increasing the driver's workload, their results showed that the driver had to process more information. This can lead to a situation where the driver is distracted from focusing attention on dealing with one or more important driving tasks and so decrease performance in that task.

In conclusion, an individual's workload can affect performance and the risk of getting distracted from attending to the primary driving tasks. When the optimal workload limit is exceeded due to involvement in secondary tasks when driving,

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[7] http://www.engadget.com/2013/06/26/intel-cognitive-workload-distracted-drivers/

there is the risk that the driver can be distracted and be compelled to assign resources to the secondary tasks in favor of the important primary tasks. This can lead to decreased performance in the primary tasks which may compromise the safety of the vehicle passengers.

The next section of this thesis delves into an aspect of human behavior which can be used to understand how different individuals handle workload. This relates to allocation of attention.

2.4 ATTENTION

Williams James, a famous psychologist highlighted that:

"Everyone knows what attention is. It is the taking possession of mind in clear and vivid form, of one out of what may seem several simultaneously possible *objects or trains of thought* …… It requires withdrawal from some things in order to deal effectively with others" (James, 1890, pp. 403-4).

The need to withdraw attention from some things to deal with others can arise when individuals are faced with the need to distribute attention resources during increased workload. Withdrawal of attention can be visual, auditory, cognitive or physical. It can be suggested that it is the withdrawal of attention which is referred to as distraction and so by understanding attention in some depth, it is possible to understand distraction better. For example, when there is a higher demand in a visual task, e.g. looking at the forward road, then there is likely to be more attention allocated to looking at the forward road when compared to looking at the side mirrors or even a physical task e.g. tuning the radio. This means that the driver may be distracted from attending to the forward road if attention is then shifted to tuning the radio.

Allocating attention resources can be based on task demands such that more demanding tasks would receive a higher level of attention than less demanding tasks. These attention resources according to Wickens (1992) are the mental and/or physical effort supplied by an operator to process a given task. The way individuals e.g. in the driving case, the driver, chooses to allocate attention to tasks performed at the same time can vary. For example, Preece et al. (1994) indicated that the ability of humans to attend to one event from what amounts to a mass of competing stimuli in the environment has been termed as “focused attention”. Here, there is attention targeted on one task so that the task is completed before attending to another task. Therefore, the individual would refer to different information which is only relevant to the task and intentions at that given time.

There is also the situation where there is attention on multiple tasks at the same time when there is workload increase which can result in “divided attention” (Preece et al., 1994). Here, there is concurrent allocation of attention to different tasks which are performed and the individual switches attention between the tasks so that one task has priority over others within a given period of time. It is possible that most individuals can multitask easily when there is increase in workload but they may be prone to distraction because they would not be able to adequately focus their attention. When they return to a suspended activity, it is likely that they may forget where they initially were in the activity and restart from a different point rather than where they left off e.g. monitoring the road scene for hazards after being interrupted by a voice command from a navigation system. It is also possible they may forget that they had already performed an action and repeat it e.g. looking at the mirrors. Preece et al. (1994) suggested that this most frequently occurs for routine procedures where knowledge for carrying out such tasks has become largely automated. In most cases, individuals will continually switch their attention between the various tasks instead of performing and completing tasks in a serial manner.

A further attribute of attention is that it is either voluntary i.e. when people make conscious efforts to change their attention, or involuntary i.e. when salient characteristics of the competing stimuli grab our attention (Preece et al., 1994). In complex tasks such as driving there is often voluntary shifting of attention between the different tasks because the driver has to monitor a wide range of tasks to safely control the movement of the vehicle on the road e.g. changing gears, looking in the mirrors, turning the steering wheel, looking at road signs etc. Attention to secondary tasks can be voluntary if the driver willingly decides to switch attention from the primary tasks. It can be involuntary if a competing entity which grabs the driver's attention also complements the primary task. Therefore, the driver would not make any conscious effort to switch attention between the tasks.

2.4.1 ATTENTIONAL RESOURCE THEORIES

Several workload theories have been developed which provide an understanding of how people allocate their attention resources under different workload conditions. The attentional resource theories which have been outlined in the literature include the 'Limited Resource Theory', 'Multiple Resource Theory' and 'Malleable Attentional Resource Theory'.

The Limited Resource Theory

In the Limited Resource Theory (LRT), it is believed that resources are limited and their deployment is under an operator's voluntary control (Wickens, 1984). It is suggested that a linear relationship exists between the amount of resources allocated and performance in a task. Therefore, when resources are invested in performing a task, the relationship between the amount of resources invested and the performance in the task would remain linear until the point where all of the resources are invested in the task after which it would be impossible to invest any more resources. At this point performance in the task would remain stable provided there is no increase in the complexity of the task. Any decrement would likely be noticed when the limited amount of resources which are available to the individual are used up and the task complexity increases. This would result in sharing of the resources based on the task demand in order to achieve an acceptable level of performance.

Irune (2009) suggests that the impact of too much workload when executing a task which is using a resource is that errors and slower performance in the task can be obtained. For example, if there is no excess demand for using a resource in the driving task, the driver's simultaneous involvement in other tasks which require the same resource can cause excess workload. Also, if there is demand for attention resources from a task which requires immediate attention and the resources are not allocated accordingly, then there is the possibility that there may be a delay or failure to acknowledge that an action is required which can lead to error or poor decision making. Yang (2011) pointed out that this theory helps to explain why once the resource limit has been reached e.g. when performing “harder” secondary tasks then performance in the primary and/or secondary task decreases.

The Multiple Resource Theory

Wickens (1984) proposed the Multiple Resource Theory (MRT) where the resources are divided into “resource pools” and suggested that the different types of resources are used for different modalities (e.g. visual or auditory) when performing tasks. There is a suggestion that a central processing resource exists to perform all types of tasks and that when two tasks have an overlap in terms of resource requirement, either the primary or secondary task or both will be affected since the resource will become fully allocated. Also, when two tasks require different resources, for example, when one is visual and the other is auditory, there will be no direct conflict of the resources unless the performance of either task is constrained by the central resource limitation. The proposed structure of processing resources is shown in Figure 2.3.

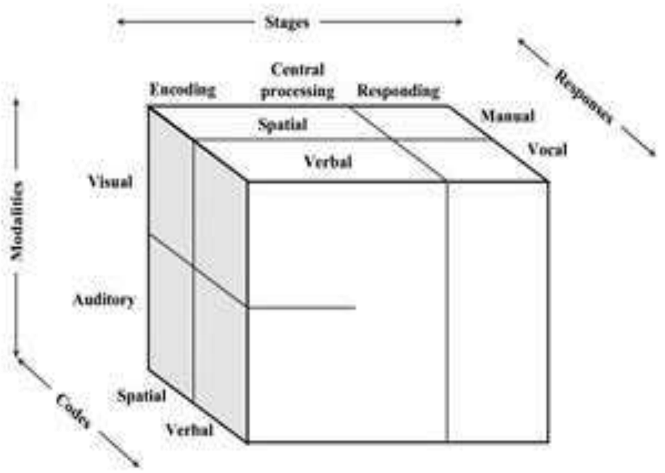

Figure 2.3: The proposed structure of processing resources (Wickens, 1984)

The figure above shows how the concept of multiple resources can be represented as points in a three-dimensional space; the axes represent the modalities (visual or auditory) used to input information, associated codes (spatial or verbal), different stages of information processing (encoding, central processing, responding) and types of response (manual or vocal). Yang (2011) suggested that the closer two tasks are in this space, the more they will interfere with each other. This is because they would compete for the shared type of input, processing and output resources. For example, the visual display of a navigation system would interfere with viewing the forward field of view as both require visual resources for task performance. Wickens et al. (1983) indicated that in line with the MRT, performance decrements are less severe when there is concurrent performance of cross-modal tasks e.g. visual and audio-intensive tasks when compared with intra-modal ones, for example, when both tasks require density visual information processing. This is because there would be increased demand for the same type of resource which would mean that there would be sharing of available resources to ensure an acceptable level of performance in the tasks.

Angell et al. (2006) proposed a modified Multiple Resource Theory where verbal and spatial information processing are considered as working memory types in dynamic control tasks such as driving. According to Baddeley (1986), this working memory is “a temporary storage for information processing while tasks are being performed”. In the driving task, drivers require an essential knowledge of the speed, position and acceleration of vehicles around for which spatial working memory is useful. This would enable them to adjust their steering wheels and pedals using manual controls to avoid collision with the other vehicles. Verbal working memory can be useful for performing tasks which include reading road signs or listening to information from a radio, navigation or entertainment systems. From the Multiple Resource Theory, these actions correspond to the three dimensions of visual information modality, spatial working memory and manual response. De Waard (1996) suggested that secondary tasks which fall into the same dimension as “normal” driving would be expected to have the highest overlap of resources and the higher competition for these resources will occur and cause the highest driver workloads.

The Malleable Resource Theory

The Malleable Attentional Resource Theory (MART) was proposed by Young and Stanton (2004) and was used to describe the mental underload when using automated systems. Automated systems usually perform well when the human operator easily adapts to them but the operators are often not prepared to cope with sudden change. Yang (2011) outlined that the Malleable Attentional Resource Theory contains three basic rules:

- The attentional resources are malleable
- The attentional resources are linked to task demand
- There is a lag in the attentional resource expansion

The implication of these rules is that when task demand is reduced the attentional resource pool shrinks to accommodate the reduced demand (i.e. the resource pool is malleable). This is seen as being cognitively efficient by Young and Stanton. Also they indicated that when an increase in workload demands suddenly occurs to the human operator, it would be difficult for the operator to cope with the requirement because the resource pool cannot expand quickly. As a result, there would be a negative impact on the performance of the task.

In summary, allocating attention is vital for dealing with workload. In the driving task, drivers are likely to allocate attention to tasks which they assign a higher priority. A related topic when dealing with how attention is allocated during performance of tasks is that of distraction. The next section provides insight into the concept of driver distraction which often occurs when the driver is engaged in performing secondary tasks while driving.

2.5 DRIVER DISTRACTION

Distraction can be described as a common driver problem. The complex and dynamic nature of the settings inside and outside the vehicle and tasks performed by drivers often create a difficult situation for the driver. With technological innovations in in-car information systems, the driver distraction problem has been made even more complex due to the increasing number of systems afforded to the driver. Interacting with these systems whilst performing a complex task such as driving can increase the driver’s workload and cause them to divide and distribute their attention amongst the tasks performed. Driver distraction can be a difficult problem to address because it can be motivated by a wide range of factors. One outcome of this has been the lack of a common definition for the term as indicated by Regan et al. (2009). They suggested that this would have been caused by different distraction studies examining different distraction phenomenon and as a result have led to disparities in their outcomes.

2.5.1 DEFINITIONS OF DRIVER DISTRACTION

Several definitions for the term have been provided. For example, Tasca (2005) proposed a working definition after reviewing definitions from previous authors including Ranney et al. (2001); Stutts et al. (2001), Beirness et al. (2002) and Green (2004). Tasca stated that distraction occurs when there is:

- A voluntary or involuntary diversion of attention from primary driving tasks not related to impairment (from alcohol/drugs, fatigue or a medical condition).
- Diversion occurs because the driver is:
    - Performing an additional task (or tasks) or
    - Temporarily focusing on an object, event or person not related to primary driving tasks.
- *Diversion reduces a driver's situational awareness, decision making* and/or performance resulting in any of the following outcomes:
    - Collision
    - Near-miss
    - Corrective action by the driver and/or another road user

Also, in 2005, delegates of the first international conference on distracted driving recommended a definition which was agreed would provide a sound basis for future research even though it was necessary to formulate a simpler definition for certain audiences. The definition, published in April 2006 (Hedlund, Simpson & Mayhew, 2006, p.2) took several definitions from authors including Ranney et al. (2001), Stutts et al. (2001), Hedlund (2005), Smiley (2005) and Tasca (2005) into consideration. They stated in their definition that:

- "Driver distraction involves a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or *event not related to driving, which reduces the driver's awareness,* decision making, and/or performance leading to an increased risk of corrective actions, near crashes or crashes".

A more comprehensive definition of driver distraction was provided by Pettit et al. (2005) where they considered the taxonomic properties of distraction based on an in-depth analysis of crash data. They looked at the driver behavior components (i.e. what the driver does) along with performance components (i.e. the results of being distracted). They highlighted that four aspects must be covered in a comprehensive definition for the term: the difference between distraction and inattention, the recognition that distraction can be internal or external to the vehicle, that distraction can be categorized into four types and the effect of distraction on the driving task. They then proceeded to provide their own definition for driver distraction after conducting a review of definitions in current literature. They stated that driver distraction occurs when:

- A driver is delayed in the recognition of information necessary to safely maintain the lateral and longitudinal control of the vehicle (the driving task) (**Impact**)
- Due to some event, activity, object or person within or outside the vehicle (**Agent**)
- *That compels or tends to induce the driver's shifting attention away from* the fundamental driving tasks (**Mechanism**)

- *By comprising the driver's auditory, biomechanical, cognitive or visual* faculties or a combination thereof (**Type**).

The definitions for driver distraction provide some indication of the nature of the problem. They can be summarized to suggest that there is primarily a shift of attention away from the road to a competing entity which is inside or outside the vehicle. This usually has an effect on the performance of the primary driving tasks. When distracted, it is possible that a driver may encounter different types of distraction. The next section unpacks the different types of distraction with the aim of providing a broader understanding of how distraction can occur.

2.5.2 TYPES OF DRIVER DISTRACTION

There are four types of distraction which have been identified in research: visual, cognitive, auditory and physical (Young et al., 2003; Pettit et al. 2005; Irune, 2009; Stutts et al., 2001; Tasca, 2005; Regan et al., 2009; Ranney et al., 2001; Kircher, 2007). The visual distraction occurs when the driver looks away from the road to a competing entity which may be internal to the vehicle (e.g. a display, dial, control) or external to the vehicle (e.g. other vehicle, road sign, pedestrian, etc.). Young et al. (2003) also outlined that visual distraction can occur when a driver has his/her field of view blocked (e.g. by a windshield sticker, display, etc.) or when there is loss of 'visual attentiveness' which is also known as 'look but did not see'. Brown (1994) suggested that the impact of the visual distraction is eyes-off-the-road where there is a general withdrawal of attention and reduced visual awareness of events in the surrounding environment. This can reduce the driver's detection and reaction to changing circumstances which occur in the field of view. In literature, there are arguments regarding the extent of visual information which drivers use with suggestions that it could be up to 90% (Sivak, 1996). If the driver's ability to engage with visual information on the road is reduced then it is likely that this would affect their performance in the driving task. The visual distraction can be measured using several variables including glance duration and frequency.

The cognitive distraction occurs when the driver has his/her attention absorbed by thoughts (not related to driving) to the point where safely navigating through the road network and reaction times to events is reduced (Young et al., 2003). This can also include situations where the driver is 'lost-in-thought' or 'day-dreaming' (Ranney et al., 2001). The nature of cognitive distraction is usually such that the driver might receive information from various sources but would fail to allocate processing resources to interpret the information received because there is attention on something else. Tasca (2005) suggested that because humans have limited processing capacity, we can only attend to one task at a time. Therefore, when performing a complex task such as driving which usually demands concurrently attending to several tasks there is an increased risk of cognitive distraction. Brown (1994) suggested that the impact of the cognitive distraction is mind-off-the-road where there is a selective withdrawal of attention based on perceptual interpretation or decision selection.

The auditory distraction occurs when a driver momentarily or continually focuses attention on sounds or audio signals rather than the road environment (Young et al., 2003). The source of the auditory distraction may be internal to the vehicle (e.g. music from an entertainment system, conversation with other passengers or spoken commands from a navigation system) or external to the vehicle (e.g. noise from road works, other vehicle horn or siren). Depending on how the audio information is significant to a driver, it compels the driver to listen and react to a situation e.g. danger, pleasure or perform optimally in a task. Several factors can affect the level of the auditory distraction for a driver, for example, the timing, complexity or tone of the information. Burnett (2000) suggested that poorly timed messages can often cause drivers to inappropriately react to situations and make errors. The complexity of the information can affect the time which the driver spends listening to the instructions such that longer messages which are difficult to understand would imply more time and attention is diverted from attending to the driving task when compared with short messages. The tone of the information can affect the ease with which the driver can understand what is being said in the message.

The physical or biomechanical distraction occurs when a driver moves his/her body away from the standard posture needed to perform the physical task associated with the safe control of the vehicle (Young et al., 2003). They suggest that the driver usually takes his/her hands off-the-steering wheel to manipulate a control or dial, key information into a display or reach out to grab an object (e.g. on the passenger's seat or dashboard etc.). It is possible that the physical distraction reduces the driver's control over the tasks which are performed because the driver would be unable to manipulate the tasks e.g. steering, indicating, etc. because they do not have their hands on the steering wheel.

It is possible that the driver may experience more than one type of distraction at any given time. Pettit et al. (2005) shared this view and they outlined that whilst all four types of distraction are useful, it is important to recognize that they are not mutually exclusive. It can be possible for complex tasks to involve more than one type of distraction e.g. when using a vehicle satellite navigation system where the driver may look away from the road to the visual display, listen to the spoken commands which provide instructions on what to do and process the information in order to make a decision. This would be less common with a simple task such as turning on the indicator which would likely involve only taking hands off the steering wheel.

2.5.3 SOURCES OF DRIVER DISTRACTION

It is possible for drivers to be distracted by anything in their surrounding environment which has the capacity to draw and retain their attention for a given period of time. Stutts et al. (2001) and Glaze and Ellis (2003) categorized sources of distraction based on several entities which were identified to have an impact on the driver. Stutts et al. (2001) analyzed data which was collected from the Crashworthiness Data System (CDS) to identify the commonly reported distractions amongst distracted drivers. They revealed that ‘distractions external to the vehicle’ (e.g. people, objects or events) were the most frequently reported source of distraction (29.4%). This was closely followed by ‘other sources of distraction’ (25.6%) and adjusting the radio/CD player (11.4%). Distractions relating to smoking were the least reported source of distraction (0.9%). A list of the sources of distraction which they identified is provided in Table 2.2.

Table 2.2: Specific sources of distraction (Stutts et al. 2001)

Specific distraction	**% of drivers**
Outside person, object or event	29.4
Adjusting radio, cassette or CD player	11.4
Other occupant in the vehicle	10.9
Moving object in the vehicle	4.3
Other device or object brought into the vehicle	2.9
Adjusting vehicle or climate controls	2.8
Eating or Drinking	1.7
Using or dialing cell phone	1.5
Smoking related	0.9
Other distraction	25.6
Unknown distraction	8.6

Glaze and Ellis (2003) analyzed data from crash records collected by troopers for the Virginia Commonwealth University. They identified the most commonly reported distractions which contributed to crashes in Virginia. Their list of distraction sources was different from that of Stutts et al. (2001) with more distraction sources identified e.g. they revealed that ‘other distractions inside the vehicle’ were the most common source of driver distraction reported and pagers were the least reported source of distraction. Their list of distraction sources is shown in Table 2.3.

Table 2.3: Distraction sources: Glaze and Ellis (2003)

Distraction source	**% of reported distractions**
Passenger or children distraction	8.7
Adjusting radio, cassette or CD player	6.5
Eating or drinking	4.2
Using or dialing mobile phone	3.9
Adjusting vehicle or climate controls	3.6
Other personal items	2.9
Smoking related	2.1
Document, book, map, directions, newspaper	1.8
Unrestrained pet	0.6
Grooming	0.4
Technology devices	0.3
Pager	0.1
Other distractions inside the vehicle	26.3

It can be seen that similar sources of driver distraction were highlighted by both sets of authors. However, Young et al. (2003) outlined that the differences in results from the two groups could have resulted based on several factors. Firstly, there was a difference in sample size (Glaze and Ellis performed their analysis on a smaller sample size when compared with Stutts et al.). There was also a difference in the methodology used to obtain the data (Stutts et al. obtained their data from the Crashworthiness Data System which was vehicle-based while the data used by Glaze and Ellis was obtained by troopers completing surveys for each crash they attended). Also, the data used by Stutts et al. (2001) was obtained between 1995 and 1999 while the data used by Glaze and Ellis (2003) was obtained during the last half of 2002. Finally, use of certain devices (e.g. mobile phones) had risen between the times when the two groups conducted their analysis. This was considered to be a major reason why certain devices were more commonly reported by Glaze and Ellis (2003) when compared to Stutts et al (2001).

The sources of distraction which were reported were likely to be only those which the drivers in each case were exposed to. For example, Glaze and Ellis (2003) reported less about the distractions which are external to the vehicle e.g. road signs, other vehicles, buildings, pedestrians etc. It is possible that these can cause distraction to the driver (e.g. based on colour, shape, height, illumination etc.). Also, Stutts et al. (2001) accounted for distractions under broad categories (e.g. objects brought into the vehicle) instead of specifics (technology devices, maps, newspaper, documents, toys etc.). It is not clear what is regarded as 'other distractions' and 'unknown distractions' as reported by Stutts et al (2001). This could suggest that the lists which were provided by the two groups are not exhaustive and perhaps supports the statement made earlier which outlined that it is possible for anything to distract the driver.

Young et al. (2003) emphasized on a critical aspect of the work done by these two groups. They stated that because there is no exposure data available, it is not possible to determine the relative levels of distraction which are afforded by the various sources of distraction. This could mean that even though a particular source of distraction may be more commonly reported than others, it may not necessarily have a more adverse effect on the driver. They suggested that experiments which compare the distracting effects of two or more in-vehicle tasks should be able to provide a clearer picture of the relative levels of distraction which are afforded by different distractors.

The sources of distraction which were outlined by both sets of authors clearly indicate that they are either technology-based or non-technology-based. Vehicle satellite navigation systems can be categorized under the technology-based distractions. There has recently been developments in vehicles where it is possible to display information on the windshield and these have been specifically targeted to address visual concerns with dashboard-mounted systems e.g. vehicle satellite navigation systems. This format for displaying information on the windshield is known as a head-up display (HUD).

2.6 HEAD-UP DISPLAYS

Head-up displays (HUDs) are becoming increasingly used to present information to drivers on the windshield. Foyle et al. (2005) describes a head-up display as “a collimated, transparent display medium upon which graphical information or superimposed symbology can be presented”. Tönnis et al. (2005) highlighted that head-up displays take icons and texts that are usually found on the dashboard and displays them on the windshield, helping drivers to keep their eyes on the road. Information e.g. for collision avoidance, route guidance and speed can be presented on the windshield of the vehicle as a head-up display. According to Ververs and Wickens (1998), the head-up display instrumentation is generated by a CRT and displayed through a combiner glass located in the line of sight of the pilot. For vehicles, this would be the driver. Due to safety concerns e.g. occlusion of the background scene, the head-up displays are usually presented in a limited region of the windshield and are different from full windshield displays (FWD) which use the full windshield to present information (Wen et al. 2009).

Head-up displays were originally used by the military but have now begun to find commercial use in vehicles[8]. They are also used in aviation where pilots are provided with information on the windshield of the cockpit (e.g. McCann and Foyle, 1994). Many vehicle manufacturers now have a head-up display in their vehicles for the driver. Some examples of these are shown in Figures 2.4[9,10], 2.5[11], 2.6[12] and 2.7[13].

Figure 2.4: Visual Navigation (vNav) head-up display

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[8] http://en.wikipedia.org/wiki/Head-up_display

[9] http://uci-info-viz.blogspot.co.uk/2010/04/visual-navigation-vnav.html

[10] http://w-info.blogspot.co.uk/2013/05/hud-head-up-displays-windshield.html

[11] http://crossmediaaugmentedreality.wordpress.com/category/augmented-reality-introduction/

[12] http://www.inautonews.com/lexus-head-up-display#.UyCIKoWEd2E

[13] http://www.gmhightechperformance.com/hotnews/1309_2014_camaro_convertible_debuts_in_germany/photo_08.html

Figure 2.5: BMW head-up display

Figure 2.6: Lexus RX 450h head-up display

Figure 2.7: Chevrolet Camaro 2014 head-up display

Head-up displays provide several advantages to the driver including reducing the scan area of attention, focusing visual attention on the forward road which can lead to better detection of critical events on the road and rapid response times to events (McCann and Foyle, 1994; Ververs and Wickens, 1998; Yeh and Wickens, 2000; Foyle et al. 1995; Liu and Wen, 2004; Charissis et al. 2008; Gish & Staplin, 1995).

Reducing the scan area of attention

With driving information required to perform several tasks displayed on the windshield, the driver does not have to look away from the field of view to obtain information. Crawford and Neal (2006) highlight that head-up displays require reduced scanning of information because the information is “head-up”. In aviation, McCann and Foyle (1994) suggested that with a head-up display, the pilot can monitor instrument information and the far visual scene in parallel so that they can visually attend to the forward field of view whilst also processing the head-up display information. Ververs and Wickens (1998) indicated that the location of the head-up symbology yields an information processing advantage by reducing the scan area of the pilot such that the elevated position of the instrumentation allows pilots to easily switch attention between the two sources of information without having to reorient attention back inside the cockpit. Reducing the scan area for the required driving information can enable the driver to easily monitor the road scene for changing situations.

Focusing visual attention on the forward road

Having information displayed on the windshield can help to focus the driver’s attention on the road. For example, Yeh and Wickens (2000) highlighted that the ability to present information superimposed on the user’s field of view e.g., the presentation of guidance symbology, reduces the amount of time which the operator would have spent head down accessing this information e.g. from the dashboard of a car or a hand-held display. Also, that if the display is collimated with the field of view then there can be reduction in the amount of eye accommodation required for switching focus between the near domain (symbology) and far domain (world). This can help improve the driver’s awareness of the surrounding environment. Foyle et al. (1995) suggest that being able to focus on the forward field of view has been useful for precision landing in aviation.

Reduced response times

With attention focused in the forward field of view, this can help to improve detection and reaction to events. For example, Liu and Wen (2004) found that head-up displays supported faster response times to urgent events on the road and required less mental workload when compared with head-down displays (HDDs) e.g. dashboard-mounted navigation systems. Also, Charissis et al. (2008) highlight a number of live trials that were conducted by researchers which demonstrate that superimposing useful information in a head-up display can lead to rapid and stable driving responses when compared with traditional instrument panels or head-down displays (Kiefer, 1991, 1995; Hooey & Gore, 1998; Gish & Staplin, 1995). Ververs and Wickens (1998) indicated that the colocation of information facilitates processing through efficient allocation of attentional resources.

Despite these benefits of head-up displays, several issues of concern still surround their use e.g. cost, size and placement, misaccommodation effect, information clutter, background scene complexity and attention capture (Ward and Parkes, 1994; Schwartz, 1983; Stokes et al., 1990; Crawford and Neal, 2006; Foyle and McCann, 1993).

Cost

According to the Wall Street Journal, head-up displays are relatively costly as figures indicate that they are worth around £700 on average and are offered as part of an optional package[14]. It can be suggested that this high cost could be a limiting factor for the potential growth of head-up displays. The Wall Street Journal suggests that for head-up displays to be commercially available to a large population of drivers, there would probably have to be a lowering of the system specifications. Also, that growth in the use of head-up displays may depend on the amount of money which the drivers would be willing to spend on these types of systems and their upkeep.

Size and placement

The size and placement of the head-up display information should be an important design consideration. Gibson (1980) and Schwartz (1983) highlight that there is a limited envelope within which the HUD information is visible. This is considered by Haslegrave (1993) to be a limiting factor given the anthropometric range of drivers. The size of the head-up display should allow the driver to easily detect the image without difficulty. It is possible that the image may obstruct and/or distract the driver from clearly seeing occurrences in

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[14] http://blogs.wsj.com/drivers-seat/2013/01/26/car-makers-take-a-serious-look-at-head-up-displays/

the forward view if it is too large. The driver may also struggle to see the image if it is too small such that it is possible that additional glances may be made to grasp information.

Furthermore, the position of the head-up display in vehicles should be made adjustable so that it is possible for the driver to optimize positioning. For positioning of the head-up display, Ward and Parkes (1994) suggested that having the HUD information superimposed on the road may avoid the possible detrimental effects of superimposing it on the complex background scene. However, it is also possible to consider what part of the road scene the image is superimposed to ensure that it can be well used. This could be where the adjustable feature may help with the head-up display image.

Misaccommodation effect

Crawford and Neal (2006) suggest that misaccommodation of the eyes occurs when focus is drawn inwards by something close. This can affect the ability of a person to detect objects at a distance and the appropriate size of the objects. Crawford and Neal suggest that collimation is often employed to correct this issue of misaccommodation with head-up displays. They indicate that the collimation is intended to put the head-up display symbology at the same optical depth as the external world which in principle should assist with the accommodation problem and reduce the time to refocus. By putting the object at the same optical depth as the external world, the pilot can shift attention to the outside world rather than focus on the near domain.

There is the argument surrounding the impact of collimation in aviation as to whether it pulls the pilot’s focus outward or not (Hull, Gill and Roscoe, 1982;

Iavecchia, Iavecchia and Roscoe, 1988, Norman and Ehrlich, 1986; Weintraub and Ensing, 1992). There is not much evidence to show that collimation does not cause focus to be pulled outward as suggested by Weintraub and Ensing, (1992) but this has to be used carefully in design to avoid causing usability issues for different users. There is also the problem which is highlighted by Crawford and Neal (2006) regarding whether the combiner glass of the HUD and its frame and lack of movement compared with that of the external world can cause misaccommodation. Roscoe (1987) suggested that these items may provide perceptual clues that the HUD is closer than the outside world even though Crawford and Neal (2006) suggest that there is no strong evidence available to assess whether the combiner glass significantly increases the risk of misaccommodation.

Information clutter

Presenting too much information in the driver's field of view can cause "information clutter" according to Edquist (2008). The driver requires a clear view of the road to perform the visual tasks properly and Edquist (2008) suggests that visual clutter can affect driver workload as well as purely visual aspects of driving e.g. hazard perception and search for road signs. Newman (1987) indicated that it is possible that HUD-presented text, symbology and images can perceptually mask critical information in the outside world. Ververs and Wickens (1996) highlighted that clutter cancels out some of the benefits of head-up displays. This can cause problems for the driver because it is possible that when the field of view is cluttered with the information from the head-up display then the driver may fail to detect critical information which is needed to perform a given task.

Furthermore, it is possible that high visual clutter may increase the visual scanning pattern of the driver. For example, Burnett and Donkor (2012) examined different levels of complexity with varying amounts of information and found that higher levels of complexity and information increased the number of objects the drivers had to look at whilst driving. These were located at different parts of the windshield and so there were increased eye movements across the field of view as the amount of information increased. Stokes et al. (1990) suggested that information clutter is an important consideration for head-up displays because the visual background is rich in rapidly changing color contrast and it may be worsened when the presented information not only competes but also conflicts with the information in the outside world.

Background scene complexity

The head-up display information would be projected against a background scene in the driver's field of view. Cole and Hughes (1984) highlighted that when contemplating implementation of a head-up display in a vehicle, the consequences of display illegibility are more pertinent due to background complexity against which the information is likely to appear within the driving environment. If the number or complexity of the head-up display information is increased over a complex background scene it is possible that there would be an adverse impact on the ease of retrieving information from the head-up display. There are several studies which have found this to be true (Benel and Benel, 1981; Cole and Hughes, 1984; Monk and Brown, 1975). These studies indicate that the background scene complexity can have an effect the driver's perception of the head-up display information.

The findings from the studies suggested that it would be difficult to detect information in a head-up display in areas of high visual complexity. For example, it is possible that in high traffic on the road or low visibility, displaying information in the driver's field of view may cause problems which can make the head-up display unusable. Ward and Parkes (1994) indicated that it should be reasonably expected that the legibility of the head-up display information presented to the driver would deteriorate as the visual complexity of the driving environment on which the information is superimposed is increased.

Attention capture

Finally, there is the issue of attention capture which the driver has to deal with when the head-up display information is in the field of view. This attention capture can be visual or cognitive (Zwahlen, 1985; Weintraub, 1987; Ward and Parkes, 1994). Zwahlen (1985) suggested that there is a high level of visual attention which the driver has to allocate to the outside world. It is possible that overlapping information in the same visual space can result in visual capture. In aviation for instance, Foyle and McCann (1993) indicated that there were occasions where pilots failed to attend simultaneously to both the HUD symbology information and the outside world information due to visual capture. Also, Foyle et al. (1995) suggested that there were studies in aviation which showed that although the head-up display symbology supported precision landing, the pilot was not necessarily simultaneously looking at the symbology and out-the-window-scene. This attention capture may have resulted in an inward focus which is also suggested by Roscoe (1987) so that less attention was focused on the background scene.

Apart from the visual capture the driver may also deal with cognitive capture. This cognitive capture according to Weintraub (1987) is “the tendency of head-up displays to monopolize visual attention and thereby interfere with a driver’s navigation ability”. Ward and Parkes (1994) highlighted that humans may not be accustomed to dividing attention equally between information which is superimposed in the same space. This would cause them to focus on one source of information over the other. It is possible that information which has a high tendency to affect the driver’s cognitive processing of information from the forward road can increase the risk of attention capture which can reduce awareness and detection of events in the road scene for the driver. The driver’s processing resources may be shifted from processing information on the road to that from the head-up display image on the windshield. This can reduce the driver’s performance in the affected task.

The issues which have been discussed concerning head-up displays should be carefully considered when designing future head-up displays as it is possible that they can affect their usability. There is also the impact on the driver’s workload and risk of distracting the driver’s attention from the road scene which should be considered to ensure that the head-up display does not affect performance in the primary driving tasks. Ward and Parkes (1994), suggest that there should not only be consideration of the functional characteristics of a display but also the types of information content that should be conveyed because of the impacts which it can have on the driver.

One aspect which is finding increasing application in the design of information systems for vehicles is augmented reality. The next section examines the concept of augmented reality and looks at the potential benefits which it can offer designers of vehicle systems to possibly deal with the issues of workload and distraction. This technique is also relevant in this research as it is applicable to the design concept which is introduced.

2.7 AUGMENTED REALITY

Augmented reality (AR) is a part of HCI and Silva et al. (2003) point out that it is within a more general context termed Mixed Reality (MR), which refers to a multi-axis spectrum of areas that cover Virtual Reality (VR), AR, telepresence, and other related technologies. Feiner et al. (1993) indicate that augmented reality presents a virtual world which is used to enrich rather than replace the real world. Azuma (1997) highlights that augmented reality allows a user to see the real world with virtual objects superimposed upon or composited with the real world. Furthermore, Behzadan and Kamat (2008) highlight that augmented reality consists of real (existing) objects and virtual (simulation) objects displayed in a single scene. Augmented reality does not create a simulation of reality instead there is information added to the real world which enhances the meaning and experience for an individual in performing a task. In terms of its application in the driving context, Yeh and Wickens (2000) point out that the need to present drivers with complex information has led to display enhancements which allow a more efficient presentation of data through a more “invisible” interface which use techniques of augmented reality where there is supplementary information relevant to the driving task at hand referenced to the real world beyond.

The concept of augmented reality was pioneered by Ivan Sutherland (Sutherland, 1968). His system presented graphics to a user on a pair of stereo displays which was worn on the user's head. The graphics was combined with the user's view of the real world using mirror beam splitters. A 3D tracking system was used to determine the position and orientation of the user's head which enabled it to change the view depending on where the user was facing (Feiner, 1996). An example of an augmented reality is a scene developed from raw sensor data onto which textured polygons are mapped to create a "real" world view and such an image may be augmented by cueing symbology which calls attention to interesting aspects of the visual scene (Drascic & Milgram, 1996; Milgram & Colquhoun, 1999). Other research in augmented reality have been targeted to address concerns in areas including aircraft cockpit control (Furness, 1986), assistance in surgery (State et al., 1996), viewing hidden building infrastructure (Feiner et al., 1995), maintenance and repair (Feiner et al., 1993) and parts assembly (Caudell and Mizell, 1992; Webster et al., 1996). An example of augmented reality is shown in Figure 2.8[15].

Figure 2.8: The MVS True 3D virtual cable augmented reality navigation system

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[15] http://www.mvs.net/

In the Figure above, the red virtual cable which is displayed above the driver's view of the road is augmented with the real world in order to provide route guidance information to the driver. The cable moves along the route which the driver should follow thereby allowing the driver to continuously monitor the road scene whilst also obtaining the required navigation information. The True 3D virtual cable navigation system won top prize at the European Satellite Navigation Competition in Munich, Germany in 2011.

Wickens and Baker (1995) suggest that there are two types of views which the user can be presented with in augmented reality systems; egocentric and exocentric views. They indicate that in the egocentric view the user is immersed in the display and views and interacts with the real or virtual world from his own perspective whereas the exocentric view provides a view from a point fixed at some height above the user's current position such that the user's movement can be tracked but not his orientation. It is reasonable to suggest the egocentric view provides a more realistic view for the user when compared with the exocentric view because when immersed in a given environment users tend to engage with the objects around them from their perspective. In fact, Slater and Wilbur (1997) suggest that a system with which a user is able to interact through an immersed egocentric viewpoint is likely to improve the sense of "presence" or the "sense of being there" within a virtual environment.

Benefits of augmented reality

Augmented reality systems have several advantages for users. For example, they can be used to assist individuals who require collecting and integrating information from various sources to determine the status of a situation and take a decision. Yeh and Wickens (2000) highlight a situation where a pilot may want to identify his position whilst examining information on a digital map and searching for correspondence features in the environment. By providing additional information which meets the needs of the pilot in the field of view, the pilot can have an enhanced awareness of his position along with the features of the environment. Furthermore, there has been focus on augmented reality techniques which can precisely track objects using tethered trackers (Ward et al., 1992; Janin et al., 1993; State et al., 1996). The information provided by an augmented reality system can be tailored to meet the needs of users which can help to improve their decision making in tasks. For example, it may be necessary for a user to move away or towards objects or spaces and it is possible that if the information can be provided on a 3D scale then a better understanding of the outcome can be obtained e.g. when it regards navigation decisions in a physical space.

Augmented reality systems can also be used to provide unified information about objects. For example, Azuma (1997) suggested that there are several application areas for augmented reality e.g. military, surgery, manufacturing and entertainment where users can obtain the information they want which can be shared by other users e.g. in military aircraft when providing instruction about what should be done in a situation. There can be a similar visualization provided for users which would enable a common action to be taken and therefore can aid quick and well-tailored responses for achieving a given task. Also, when performing surgery, augmenting the patient’s body with bio-data can assist surgeons with decision making. Several other examples are outlined in Azuma (1997).

Issues with augmented reality

There can be issues with augmented reality systems as well. For example, Mosier and Skitka (1996) highlighted the issue of miscalibration in attention where attention is inappropriately allocated between two or more sources where there is focus on one source of information over another e.g. the operator who fails to monitor the rest of the visual scene for objects of interest i.e. attentional tunneling. This attention defect is a common problem for most people who may find it difficult to treat two overlapping sources of information as a single piece of information. This is because information which is presented in a near domain (e.g. by a display) can clutter the forward field of view and may obscure any information which is far away. Yeh and Wickens (2000) suggested that this miscalibration in attention may be a consequence of emphasizing certain display features (e.g. superimposing guidance symbology) such that the operators overutilize the information provided by the system, which allows performance of the task with less cognitive effort.

There can also be miscalibration of trust as suggested by Wickens et al. (1999) which can occur in one of two ways; overtrust or undertrust. The overtrust can occur when an individual feels the data which is provided by an information source is very reliable which brings about over reliance in the data and this may cause failure to seek more information when it is critical to do so. Therefore, when the information may be inadequate for a given situation and the individual fails to recognize this then action may be taken with such information which may later present challenges. On the other hand, they indicated that undertrust can occur when an individual feels the data which is provided by an information source is unreliable perhaps because it has been wrong before and this may cause failure to rely on the information even when it is appropriate to do so. As a result, the information would be ignored by the user even when it should not be the case.

Technical challenges may also be faced in the implementation of augmented reality systems. For example, Behzadan and Kamat (2008) highlight the unique challenge of having to develop methods which would be used to track the position and moving direction of objects (e.g. vehicles, pedestrians) in real time. They indicate that this would help with detecting and possibly avoiding interference or collision between virtual (simulation) and real (existing) objects. In certain driving contexts, it may be required that the virtual information should align with the real world as indicated in Hu et al. (2004) and it is possible that if this is not well achieved e.g. in a head-up display, then there may be usability issues.

Augmented reality systems particularly in automobiles are becoming more popular and it can be beneficial to explore them further to identify ways through which the driver can be provided with driving information in order to enhance the experience and performance of related driving tasks. One aspect of augmented reality which this thesis seeks to explore is scene augmentation. The next section looks at the concept of scene augmentation and how it can be useful in systems design.

2.7.1 SCENE AUGMENTATION

According to Foyle et al. (2005), scene augmentation is one of three scene-linked symbologies and an aspect of augmented reality where virtual, non-real, three-dimensional objects are drawn on the head-up display as if they existed at a location in the real world. The objects would be overlaid over the surrounding and it may be possible that objects can be collimated in the real world. An example of this scene augmentation is described by Roetting and Sheridan (2003) where there is an object added to the road scene when the driver wears a head-mounted display (HMD). The driver is able to see the object on the road as though it actually appears out on the road even though the image only appears on the display surface of the head-mounted display. Another example is outlined by Foyle et al. (1995) where in aviation "virtual traffic lights" are depicted on a head-up display which could inform a pilot as to clearance to cross an active runway during taxi. Furthermore, Foyle et al. (1992) highlight that some examples of these augmentations range from the addition of a conformal horizontal line, image processing to increase contrast (e.g. of runways), enhancing subthreshold information (e.g. distant runways, optical flow information), all the way to "making the invisible visible" such as showing graphically and spatially wind shear zones or taxis and flight paths.

In vehicles, BMW recently began working on augmented reality scene augmentations which use contact analogue displays[16]. The authors indicate that contact analogue displays are a special form of augmented reality where the displayed information is integrated into the external environment in the correct perspective and at the actual point or points in the scene to which it relates. An example of this scene augmentation is shown in Figure 2.9.

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[16] http://www.bimmerfile.com/2011/10/12/bmw-to-introduce-augmented-reality-heads-up-displays/

Figure 2.9: BMW scene augmentation with navigation information

In the figure, the driver is presented with navigation information in the form of a blue lane coloring. This information enables the driver to accurately determine at what point he/she needs to make a navigation turn.

Scene augmentations have several useful aspects. For example, Foyle et al. (1992) highlight that through scene augmentations under reduced visibility conditions or through sensor use, the pilot can use these new, augmented cues in place of the missing or degraded cues available under better visual conditions. They suggest that in the near term this augmentation can be done through a head-up display symbology, or, more practically and with more natural representations, in the long term, in an Enhanced/Synthetic Vision System. Also, a study which was conducted by Foyle et al. (2002) showed that when compared with more traditional head-up guidance displays, scene-linked symbologies produced better situational awareness, subjective ratings and improved the detection of off-nominal situation awareness probe events that occurred in the environment while also improving taxi accuracy and speed. Furthermore, Foyle et al. (2005) highlight that scene augmentation and other scene-linked symbologies can reduce cognitive tunneling and improve situational awareness. The augmentation would reduce the need to separate both information sources and as a result allow them to be treated as a single visualization.

2.8 DISCUSSION

The issues of workload and distraction are important research areas. With more work done in these areas it is expected that the issues which exist would be more understood and so there would be solutions provided to tackle the problems which have been identified. In the complex task of driving, there is usually a high level of demand on drivers to perform a range of tasks simultaneously and so designers need to take into account the nature of the driving task when providing systems for drivers to perform specific tasks. The aim would be to ensure that the execution of the primary tasks is not negatively impacting upon.

As the complexity of vehicles continues to grow, it is expected that there would be more systems provided to drivers to perform a wide range of tasks. However, the issues identified with the existing navigation systems particularly vehicle satellite navigation systems pose some issues for design to address. With regards workload these systems have the capacity to increase the driver's workload and increase the demand for attention resources. The nature of the voice commands which are used by these systems cause drivers to perform the work of translation of the instructions into situationally meaningful actions before they can be executed. In the literature, several authors (e.g. Green et al., 1995; Gartner et al., 2002; Burnett and Parkes, 1993) have suggested that integrating audio messages into these types of systems help to improve decision making and/or performance with them. However, there has not been much suggestion on how this work is actually dealt with within the driver before being utilized.

It may be useful if there is research which looks at how the cognitive work of translating the instructions is achieved to find a useful solution. Furthermore, the visual maps which drivers are provided with can increase their workload because the driver has to translate the information contained within the map into the surrounding environment in order to follow the route. The visual maps can often be complex and it is possible that complex maps would cause a significant amount of work for the drivers to understand what needs to be done. Hence, it would be useful if designers can look at other ways of providing information to drivers which would not increase their workload.

Furthermore, the ability of the driver to perform their different tasks optimally when distracted by vehicle satellite navigation systems can be affected. Distraction can occur when the driver shifts attention from the road to a distracting entity and given that many drivers may not be able to deal with the same amount of workload in the same way, it is possible that some drivers may be easily distracted more than others when engaging with in-vehicle systems. For example, Young and Regan (2007) reported that usually older drivers have a decreased ability to divide their attention effectively between simultaneous tasks because of their visual and cognitive capacity which means that they are more susceptible to distraction effects of engaging in secondary tasks when compared to younger drivers. Also, they mentioned that young novice drivers would be more vulnerable to the effects of distraction when compared with experienced drivers.

Head-up displays have been designed to shift the information to the windshield of the vehicle so that the driver can take in secondary driving information whilst also attending to the forward road. They have been found to increase the driver's visual awareness of surrounding events because of the reduced diversion of attention from the road. However, issues of misaccommodation and attention capture can occur when they are used and can affect usability of the particular systems. For example, misaccommodation can affect the driver's ability to engage with information in the road scene simultaneously when they are in different locations in the same space. Collimation has been suggested as a way to tackle this misaccommodation problem because the head-up display information would be presented at an optical depth in the real world so that both set of information appear to exist in the same space thereby reducing the need to separate them from each other. The application of this technique for designing head-up displays is not well known in automobiles but the literature suggests that it has been used in aviation to provide information to pilots which appear in the far visual scene.

The problem associated with attention capture in head-up displays is also worth considering. There is increased risk that the driver would be distracted by having information in the field of view when attending to the driving task which is highly visual in nature. Attention capture can be visual such that the driver has to look away from the road for specific periods of time when perceiving information or cognitive such that the driver focuses attention on processing the information received from either visual or audio sources. The complexity of the head-up display can increase the risk of attention capture because it is possible that systems which are more complex than others e.g. highly dynamic information, would affect drivers and cause distraction when compared to simple information which is static. The impact of attention capture by distracting entities is usually that the driver has reduced attention on the background road scene which can affect performance of tasks such as hazard detection, lane keeping, gap allocation, navigation etc. It is therefore important to address these issues in design so that drivers would be less impacted upon when driving.

Augmented reality has been used in the design of systems in areas such as medicine, architecture and aviation but there is not much work done yet with this technique in vehicles. It may be useful to integrate virtual objects in the real world to enhance task performance when the virtual objects would provide necessary information for the task. Therefore, it would be useful to study this technique more and see how its use can be applied in vehicle information systems. Scene augmentation is one aspect of augmented reality which can be used in vehicles such that there is virtual information presented to the driver on the windshield to help with performing tasks in the road scene. The example provided by Roetting and Sheridan (2003) gives an insight into how this scene augmentation can be done but it is important that such systems are carefully implemented to reduce adverse impacts of distraction on the driver. This is because the virtual objects which are added to the field of view can cause attention capture and affect detection of other objects in the field of view.

In essence, designers and researchers in the automobile systems should continue to look at ways of enhancing systems which have less adverse impacts on drivers to increase the safety of the driver in the vehicle. The existing systems may be useful for providing information to the driver but they should be improved to reduce the issues which have been identified with their use. It is important that alternative systems are developed to reduce the adverse impacts which are imposed on drivers so that they can perform their tasks better. Such work can focus on looking into new mechanisms for presenting information to drivers so that they would be less affected by workload increase and distraction which can affect their performance in the primary tasks of driving.

2.9 SUMMARY

Driver workload and distraction are critical aspects of research which are continually being assessed to reduce the issues which are affecting drivers. The proliferation of systems into the vehicle to support the driver in performing tasks optimally is useful on one hand but on the other is a cause for concern because there is the potential for increased visual, auditory and cognitive workload. This increased workload can cause driver distraction from the road which is unsafe in the driving situation. The use of vehicle satellite navigation systems and head-up displays in the driving task were examined and the issues of concern relating to workload and distraction were outlined. It is important that these issues are resolved in order to enhance the safety of the driving task for drivers. It would be useful to implement the design of an alternative interface which employs techniques for presenting information to drivers with reduced impacts on their workload and risk of distraction. This can help the driver to allocate more time and attention on the execution of the primary tasks which are necessary for the safe control of the vehicle on the road.

CHAPTER

3

ADDRESSING THE RESEARCH PROBLEM THROUGH SPECIFIC METHODS

3.1 INTRODUCTION

Having outlined the issues with current navigation interfaces which led to the suggestion in the previous chapter to design an alternative navigation interface, this chapter reviews the design process of the navigation interface along with the respective methods which were employed at each stage. At each stage, selection of the respective methods would be outlined and discussed in order to determine suitability in the development process. The review begins by highlighting the design approach which was adopted for the virtual car head-up display. This was the human-centred approach as humans (drivers) would be the eventual users of the system. It then provides a discussion on the methods employed in developing the virtual car head-up display based on the suitability to different desired criteria.

3.2 THE HUMAN-CENTRED DEVELOPMENT PROCESS

The design of the navigation interface was focused on the activities of drivers who would be its eventual users. This therefore led to consideration for the adoption of the human-centred design process in order to ensure that the end users are provided with a system which is able to meet their needs for achieving the navigation task. According to Giacomin (2012), human-centred design has its roots in ergonomics, computer science and artificial intelligence. Maguire (2001) highlights that the human-centred design (HCD) is concerned with incorporating the user’s perspective into software development process to achieve a usable system. This would enable users to be part of the development process and therefore the system which would be designed can be more tailored to suit their needs. Liem and Sanders (2011) highlight that the implication of the approach is that product development should start from a deep analysis of user needs. To achieve this Belliveau et al. (2004) highlight that in practice, researchers spend time in the field observing customers and their environment to acquire an in-depth understanding of the customer's lifestyles and cultures as a basis for better understanding their needs and problems.

A number of key HCD principles are listed by Maguire (2001). These include the following:

- The active involvement of users and clear understanding of user and task requirements
- An appropriate allocation of function between user and system
- Iteration of design solutions
- Multidisciplinary design teams

The principles recommend that involving users in the design process is useful in order to ensure that the knowledge which they possess of the contexts in which the particular tasks designed for are performed will be integrated into the design process. Maguire (2001) suggests that by integrating the users to be part of the design team, it is likely that the system would be more acceptable and that there would be more commitment from the users to use the system as the users would feel that the system is being designed in consultation with them rather than being imposed on them. Also, the responsibility of the user and the system should be distinguishable based on an appreciation of the human limitations and requirements of the task. This can make it easy for the user to know when to assume control and when to pass control over to the system, thereby enabling both to be active when the task is performed. A prototype of the system can be produced and users can test the prototype so that they provide feedback which can be used to further improve the design. Finally, by integrating different users with different expertise and experiences it is possible that the design process can be enriched. Maguire (2001) suggests that it is important that the development team be made up of experts with technical skills and those with a stake in the proposed software. Examples of experts who could be integrated into the design team can include usability experts, end users, interaction designers and task experts.

The ISO 13407 (1999) is a description of best practice in user-centred design and it provides guidance on design activities that take place throughout the life cycle of interactive systems. The goal of the standard is to ensure that the development and use of interactive systems take account of the needs of the user as well as the needs of the developer and owner to name but a few stakeholders (ISO, 1999). The standard also describes an iterative development cycle where product requirements specification correctly accounts for user and organizational requirements and specifies the context in which the product is to be used. Afterwards, design solutions would be produced and evaluated by representative users against the requirements. The ISO 13407 outlines five essential processes which should be undertaken in order to incorporate usability requirements into the software development process. The processes include:

- Plan the human-centred design process
- Understand and specify the context of use
- Specify the user requirements
- Produce designs solutions
- Evaluate design against requirements

The processes are shown in Figure 3.1.

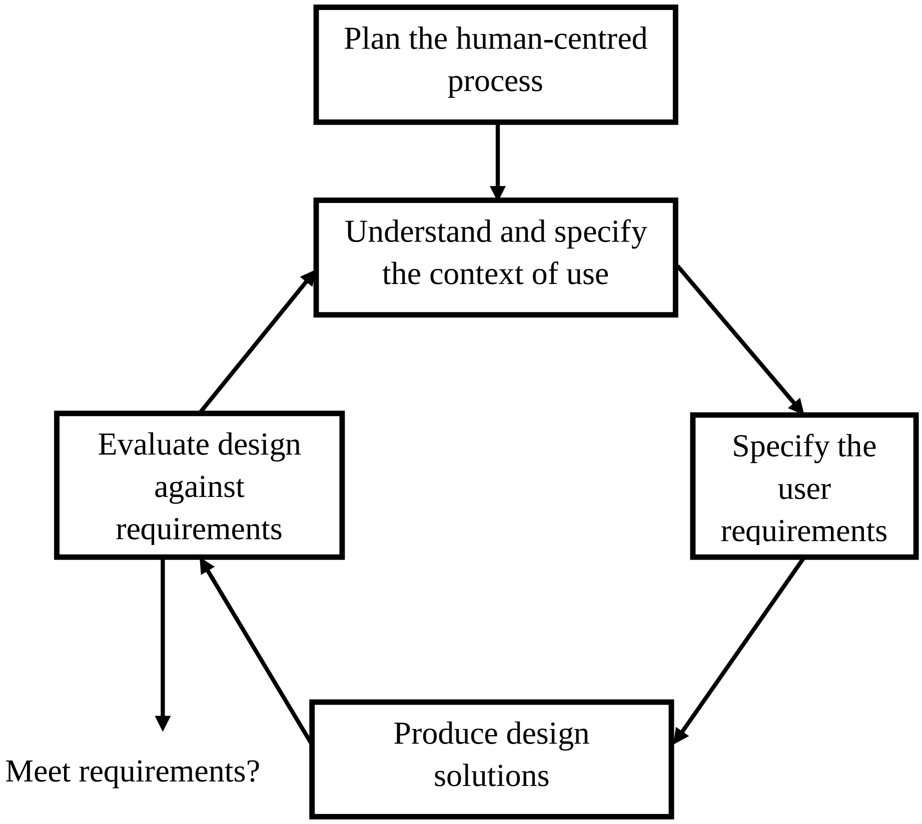

Figure 3.1: The human-centred design cycle (from ISO 13407)

3.2.1 PLAN THE HUMAN-CENTRED PROCESS

There should be careful planning and management of all parts of a system during the development process if a human-centred approach will be successful. According to various authors e.g. (ISO, 2000a; Booher, 1990; MoD, 2000), it is crucial that there is full integration of all the HCD activities as part of the system strategy for the whole of the project. The first step in planning the human-centred process involves bringing the stakeholders to discuss and agree how usability can contribute to the project objectives and to prioritize usability work (Maguire, 2001). Furthermore, performing a study to establish potential benefits to be gained from including HCD activities within the system development process and which methods to use may be necessary. These two activities are discussed as follows.

Usability planning and scoping

Maguire (2001) highlights that this could be done by bringing all stakeholders relevant to the development into a meeting in order to create a common vision of how usability can support the project objectives. In doing so, it would be possible for each of the stakeholders to highlight their concerns regarding the design and therefore lead to a better development. A number of issues can be addressed during such meeting and include but are not limited to the following:

- Why is the system designed?
- What are the overall objectives?
- How will the system work?
- What are the key functionalities which are needed by the users during the tasks?
- Who will be the eventual users and what tasks will they perform with the system?
- How will the system be judged as a success?
- What physical, social and environmental factors would affect use of the system?
- Would there be any help for users when they are faced with difficulty in using the system?
- Are there any initial design concepts?

By discussing these issues it would be possible to identify areas which need to be explored in more depth at a later stage of the development process. Maguire

(2001) highlights that one output of the meeting is a usability plan that specifies the structures to support the usability work and would highlight several aspects which include:

- Those responsible for performing usability activities (ideally a multi-disciplinary team)
- Those who will represent the users, the involvement they will have in the design process and any training they require
- The lines of communication in performing usability work between usability specialists, users, customers, managers, developers, marketing etc. This will include how to get information about the project and product to those responsible for usability, in an agreed format.

Usability-Cost benefit analysis

Maguire (2001) highlights that the aim of this activity is to establish the potential benefits of adopting a human-centred approach within the system design process. The cost-benefits can be calculated by comparing what the costs of user-centred design activities would be against potential savings which will be made during development, sales, use and support. There should be a balance so that there can be a convincing case regarding the benefits which are substantially larger than the costs of additional user activities. Maguire (2001) suggests that this can also be done by balancing the cost of the allocation of resources to the HCD against the benefits of lowered risk of system and/or project failure.

3.2.2 UNDERSTAND AND SPECIFY THE CONTEXT OF USE

Maguire (2001a) highlighted that context is an important concept in everyday life and systems which are developed would be used within a particular context.

Context is important in design as it outlines the different constraints in a task. The contexts can be used to identify the orderliness in the task which Crabtree (2001) describes as the regularity of conduct within organizations to recurring patterns of conduct. The context of use would include users with certain characteristics who would have certain goals and wish to perform certain tasks. Also, environmental factors e.g. physical, social, technical or organizational could affect the use of a system.

Maguire (2001) suggests that the quality of use of a system including usability and user health and safety depends on having a very good understanding of the context of use of the system. For example, a software application would be more usable if it is designed for use by people with different computational skills. As a result, the collection of contextual information can be useful for specifying user requirements and also for providing a sound basis for later evaluation activities. Maguire (2001) suggests that for well-understood systems, it may be sufficient to identify the stakeholders and arrange a meeting to review the context of use. For more complex systems, this may need to be complemented by a task analysis and a study of existing users.

Identifying stakeholders

A useful part of the development process would be to identify the stakeholders who would be affected by the system. It would enable their concerns to be taken into account so that the system is able to meet their needs and where possible they can test the system. Taylor (1990) suggests that users groups may include end-users, supervisors, installers and maintainers, other stakeholders (those who influence or are affected by the system) including recipients of outputs from the system, marketing staff, purchasers and support staff.

Context-of-use analysis

Maguire (2001) highlights that the context of use analysis is a structured method for eliciting detailed information about the context of use for a system as a foundation for later usability activities, particularly user requirements specification and evaluation. The information which would be obtained from analyzing the context within which a system would be used includes details about the users, their tasks, the operating environment and any other information which can affect the use of the system. The information obtained in this process can be obtained from stakeholders, however, if the information is not well understood, it is possible that other methods e.g. field studies and contextual design may be employed to collect and analyze the information. Context of use analysis was an outcome of the ESPIRIT project (see Allison et al. 1992) where a set of tools was developed which could be used to identify types of users, their needs and characteristics and translate the information into user requirements (Taylor, 1990).

Survey of existing users

A survey involves administering a set of written questions to a sample population of users (Maguire, 2001). This can be used to identify the needs of users, current work practices and how acceptable a new system idea would be to the sample population. The surveys can be made up of close-ended questions where the users are required to provide a strict answer e.g. yes or no, or open ended where the user is free to answer in a manner which they desire. This method can be used to obtain quantitative and (and often quantitative) information from a large number of users regarding tasks or systems (see Preece et al. 1994).

Field study/observation

Field studies can be conducted to study everyday life. The fieldwork conducted in these types of studies provides insight on how activities are organized in natural settings of specific tasks in real life. According to Wolcott (2005), this fieldwork is a form of inquiry in which one immerses oneself personally in the ongoing social activities of some individual or group for the purpose of research. Punch (1994) mentioned that qualitative fieldwork often employs participant observation as its central technique and this involves the researcher in prolonged immersion in the life of a group, community or organization in order to discern people's habits and thoughts as well as decipher the social structure that binds them together. The observation can be direct (or overt) where the fieldworker is actually present during the task or indirect (or covert) where the task is recorded and studied at a later time. In covert situations, the skills of the fieldworker are important to ensure that the users are able to cooperate during the observation process.

Field work is widely used in anthropology and Bronislaw Malinowski an eminent field worker in the early 20th century highlights the benefit involved in detailed participant observation for understanding human behavior. Malinowski argued that the goal of the ethnographer in field work should be to grasp the native's point of view, his relation to life, to realize his vision of his world (Malinowski, 1922). Field work can be useful in the early stages of a design process to gather requirements and understand issues to be addressed. Rogers et al. (2011) highlighted that observation when used in the early stages of design can help designers to understand the user's contexts, tasks and goals. Also, that observation can help to fill in details and nuances which are not elicited from other forms of investigation. This is because field work allows the designer to 'go out and study the contexts' which their systems would be used in therefore supporting better designs. Also assumptions would be avoided on how the system can be used.

Despite the fact that field work can be a useful technique for informing the design of user systems, Punch (1986) highlighted that it must be done carefully to avoid damaging the integrity of a field study. For example, when participants are directly observed, Punch (1986) highlighted it is important that observers do not cause the participants to experience anxiety, stress, guilt or damage to self-esteem during data collection. This can cause them to react inappropriately to situations which may defeat the purpose of the field work.

Task analysis

Maguire (2001) defines task analysis as the study of what the user is required to do in terms of actions and/or cognitive processes in order to achieve a task. Conducting a task analysis can be done to understand the current system which would be used for a task and how information flows within it. It can be useful to understand how the information flows within the system and the user actions if features and functions of the system are to be developed. If not done, there could be problems which may arise in later phases of the development process due to a lack of understanding of how the system works. After the task analysis, the functions which would be included in the system as well as the system interface and layout can be appropriately specified.

Several variations of task analysis exist which can be used for recording task activities. One of the most widely used is hierarchical task analysis where high-level tasks are de-composed into more detailed components and sequences (see Shepherd 1985; 1989). It is also possible to create a flow chart which shows the sequence of human activities and the associated inputs and outputs (Ericsson, 2001). Kirwan and Ainsworth (1992) produced a guide which shows the different tasks analysis methods. Hackos and Redish (1998) explain some of the simpler methods for user interface design.

3.2.3 SPECIFY THE USER REQUIREMENTS

Specifying the user requirements can make the design clear and easy to implement. Maguire (2001) highlights that requirements elicitation and analysis is widely accepted to be the most crucial part of software development. It can be very useful to establish and document user requirements in order that they can be used in the design of the system. The user requirements can consist of summary descriptions of the tasks which the system will support and functions which will be provided in order to support the tasks. General guidance is outlined in ISO 13407 (ISO, 1999) which can be used for specifying user requirements. It states that the following elements should be covered in the specification.

- Identification of a range of relevant users and other personnel in the design
- Provision of a clear statement of design goals
- An indication of appropriate properties for the different requirements

- Provision of measurable benchmarks against which the emerging design can be tested
- Evidence of acceptance of the requirements by the stakeholders or their representatives
- Acknowledgment of any statutory or legislative requirements, for example, for health and safety
- Clear documentation of the requirements and relation information. Also, changing information should be well managed as the system develops.

Some of the general methods for specifying user requirements include stakeholder analysis, user cost-benefit analysis, user requirements interviews, focus groups, use of scenarios (see Maguire, 2001).

Stakeholder analysis

This process identifies for each user and stakeholder group their roles and responsibilities along with the goals for their tasks. For each stakeholder who would be affected by the system, it would be useful to specify how the system would be used in order to achieve particular goals when using the system for specific tasks. Stakeholder analysis is described in more detail in Damodaran et al. (1980).

User cost-benefit analysis

According to Maguire (2001), this is a method for comparing the costs and benefits for different user groups. Here, the roles which each user group would assume would be considered and the costs and benefits would be outlined. This would be useful in providing an overview of how acceptable the system would be to each user group. It can also be useful to allow the system design or user roles to be refined so that it would be more acceptable to all groups. Eason (1988) describes a process for performing a user cost benefit analysis.

User requirement interviews

Interviews can be used to obtain requirements from different stakeholders. Maguire (2001) highlights that interviewing is a commonly used technique where users, stakeholders and domain experts are asked questions by an interviewer in order to gain information about their needs or requirements in relation to the new system. Interviews usually take a semi-structured format where fixed questions can be asked with the user being able to expand on their responses. Semi-structured interviewing can be useful when the broad issues to be asked are understood but the reactions of the respondents are not fully known. Preece et al. (1994) and Macaulay (1996) discuss how interviews can be used to obtain user requirements.

Focus groups

There is a group discussion format adopted with the focus groups where stakeholders come together to discuss issues which pertain to the system that need to be tackled. Nielsen (2000) suggests that focus groups are not generally appropriate for evaluation but the main idea is often that each participant in the group can stimulate ideas in others and through the means of discussion, the collective view becomes established which is greater than the individual parts (see Preece et al., 1994; Macaulay, 1996; Farley, 1997 and Bruseberg and McDonagh-Philp, 2001, for more information on focus groups).

Use of scenarios

Scenarios describe in a realistic manner how users perform tasks within specific contexts. According to Carroll (1999) scenarios are stories about people and their activities which provide a clear description about users and the tasks they accomplish. According to Maguire (2001), the primary aim of scenarios is to provide examples of future use as an aid to understanding and clarifying user requirements and to provide a basis for later usability testing. Carroll (1999) outlines that a scenario concretely embodies a partial view of the system and opens it up to critique in terms of the functionality and claims of how the system can be used for a task. Hence, it encourages designers to refine their ideas when developing a system by considering the characteristics of the intended users, their tasks and operating environment. It can also enable usability issues to be considered at an early stage of the design process.

Rosson and Carroll (2002) indicate that during the 1990s, scenarios were found to be especially useful in helping development teams reach sufficient agreement to enable work to proceed, and in ensuring consistency with predecessor systems. Scenarios can help with identifying usability targets and the likely times within which they would be completed. Rosson and Carroll (2002) further outlined five useful contributions of scenarios in design. They include being concrete descriptions but are flexible, are able to describe use in detail but as a tentative working representation, focus on the usability consequences of specific design proposals, describe the problem situation using natural language understood by stakeholders and offer a vivid description of use that provokes questions and what if discussions. Sutcliffe et al., (1998) suggest that even though scenario-based knowledge is generally not reusable because they are only instances of activities, they allow designers to adopt a strategy on their plan of action in design whilst also making room for further adjustments in the future.

A useful type of scenario which can highlight how users would interact with a potential system is the user-interaction scenario. Rosson and Carroll (2002) highlight that they provide a good understanding of the basic interactions which take place between users and their systems. The plot in each scenario includes a sequence of actions and events, actions of the actors, things that happen to them, changes in the setting etc. and describes what happens in each scenario. This provides an understanding of the contexts which surround the use of each system. The plot in a scenario can be used to evaluate a system which is designed based on how it accomplishes the task. There are several elements which form part of a user interaction scenario and these are provided in Table 3.1.

Table 3.1 Elements of user-interaction scenarios (Rosson and Carroll, 2002, pg 18)

Scenario element	Definition
Setting	Situational details that motivate or explain goals, actions and reactions of the actor(s)
Actors	Human(s) interacting with the computer or other setting elements; personal characteristics
Task goals	Effects on the situation that motivate actions carried out by actor(s)
Plans	Mental activity directed at converting a goal into a behavior
Evaluation	Mental activity directed at interpreting features of the situation
Actions	Observable behavior
Events	External actions or reactions produced by the computer or other features of the setting; some of these may be hidden to the actor(s) but important to the scenario

Each of the elements provides a useful piece of information which can be considered by the designers of a potential system. By understanding how each of the elements affects the use of the system, the designers can improve the eventual system design.

3.2.4 PRODUCE DESIGN SOLUTIONS

Producing a design solution is a vital part of the design process. This would allow the end product to be visualized and increase understanding of the product.

Design solutions often go through iterative development and Maguire (2001) suggests that in order to support the iterative design life cycle, mockups and simulations of the potential system are necessary. Mockups and simulations can be produced easily and used in early stages of the development process e.g. a series of user interface screens and a partial database which allow potential users to interact with, visualize and comment on the future design. These are low fidelity design prototypes but they are often followed by a high fidelity prototype (Hall, 2001). Changes can be made to the design quickly to improve it and obtain user feedback so that any problems which would affect the system use can be identified before the system development begins. This process known as Rapid Application Development (RAD) supports fast development and high quality results in the design process[17].

The RAD helps to reduce the cost of correcting design faults at a later stage in the design life cycle and therefore reduces the development costs of a system. There are usually several options available for developing a prototype of a potential system. Rosson and Carroll (2002) provide a table for the various types of prototypes which can be designed in the development process. This is shown in Table 3.2.

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[17] www.casemaker.com/download/products/totem/rad_wp.pdf

Table 3.2: Common approaches to prototyping in usability engineering (Rosson and Carroll, 2002)

Type of prototype	Description
Storyboard	Sketches or screen shots illustrating key points in a usage narrative
Paper or cardboard mockup	Fabricated devices with simulated controls or display elements
Wizard of Oz	Workstation connected to invisible human assistant who simulates input, output or processing functionality not yet available
Video prototype	Video recording of persons enacting one or more envisioned tasks
Computer animation	Screen transitions that illustrate a series of input and output events
Scenario machine	Interactive system implementing a specific scenario's event stream
Rapid prototype	Interactive system created with specific-purpose prototyping tools
Working partial prototype	Executable version of a system with a subset of intended functionality

Storyboard

Storyboards which (Nielsen, 1991) referred to as "presentation scenarios" are sequences of images which show the relationship between user inputs and system outputs. Preece et al. (2002) highlight that a storyboard is a series of sketches showing how a user might progress through a task using the device which is developed. The sketches would usually depict features of the system e.g. menus, dialogue boxes and windows and how the user employs these to achieve a given task. Maguire (2001) highlights that storyboards provide a platform for exploring user requirements options via static representation of the future system by showing them to potential users and members of a design team thereby supporting selecting and refining of requirements.

In addition, a storyboard summarizes the function of each screen and illustrates the hierarchical relationships by showing how the screens are interconnected and thereby allows the user to observe how a task might be performed[18]. Maguire (2001) highlights that the formation of these screen representations into a sequence conveys further information regarding the possible structures, functionality and navigation options which are available to users. This would allow other people to visualize the composition and scope of interfaces which are present and offer useful feedback to the designers.

Paper mockups

These paper prototypes are often created by designers where a paper-based simulation of user interface elements (menus, buttons, icons, windows, dialogue sequences, etc.) are made using paper, card, acetate and pens (Rettig, 1994; Maguire, 2001; Nielsen, 1991). There is often not much interaction which takes place here. However, it can be useful to highlight the likely response which would occur during use. Maguire (2001) suggests that when the paper prototype has been prepared, a member of the design team sits before a user and "plays the

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[18] http://www.streetdirectory.com/travel_guide/148372/programming/paper_prototyping_and_software_prototyping.html

computer" by moving interface elements around in response to the user's actions. Any issue which would be noticed during the process can be recorded or observed and used to improve the eventual design.

Wizard of Oz

The Wizard of Oz is a variant of the computer-based prototyping and a user interacts with a computer system which is operated by a hidden developer who is referred to as the "wizard" (Gould et al., 1983; Maulsby et al., 1993; Nielsen, 1993). The wizard processes the input which the user provides and simulates a particular output based on the user input. In the process, the user is led to believe that they are directly interacting with the system. Maguire (2001) suggests that this approach is particularly suited to exploring design possibilities which are demanding to implement such as intelligent interfaces possibly featuring agents or advisors, and/or natural language processing.

Video prototype

This is a variant of the paper prototype where a video-tape of the testing of the paper interface is made as elements are moved around and changed by members of the design team (Maguire, 2001; Vertelney, 1989; Young and Greenlee, 1992). The users do not interact directly with the paper prototype but would be able to watch the video tape representation at a later time. Maguire (2001) suggests that this approach can be useful for demonstrating interface layout and the dynamics of navigation particularly to larger audiences.

Computer animation

This is also referred to as software prototyping by Maguire (2001) and this approach utilizes computer simulations to provide a more realistic mockup of a system during the development process. Because of the simulation effect, there is usually more realism when compared with paper prototypes. Preece et al. (2002) suggest that a computer prototype can be described as a ‘high fidelity prototype’ which corresponds closely with the envisaged product. This means that the computer animation prototype is likely to look similar to the eventual design and would have some elements of the proposed functionality.

Scenario machine

Rosson and Carroll (2002) highlight that design issues can be demonstrated and explored using a scenario machine; a software prototype which is used to implement one or more scenarios. An example of a scenario machine is described by an author[19]. The scenario is fed into the system and the machine plays out the scenario so that people can engage with it and perform specific tasks. Information obtained can be used to improve the system being designed.

Rapid prototyping

Rapid prototyping (RP) provides a means of producing physical models directly from computer aided design (CAD) data (Campbell, 1998). The software tools used can allow the designer to create an interactive system which users can engage with and provide feedback. The technique was first used by 3D systems of Valencia, California, USA. The process can be used for visualization and testing of products[20]. There are a number of RP techniques which are currently available (see Campbell, 1998). It is useful for reducing costs at later stages of

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[19] http://courses.cs.vt.edu/~cs3724/spring2003carroll/lectureHandouts/6-prototyping.pdf

[20] http://www.efunda.com/processes/rapid_prototyping/intro.cfm

the development process by allowing corrections to the eventual product to be made at an early stage during the system development.

Partial working prototype

Also called a functional prototype[21], would aim to simulate the eventual design of a system to the greatest extent possible in terms of the aesthetics, materials and functionality. It is possible that this prototype could be reduced in size to reduce costs. This prototype would allow the designer to have a final check for design flaws and offer the opportunity to make any last minute improvements to the system before the large scale production begins.

3.2.5 EVALUATE PROTOTYPE AGAINST USER REQUIREMENTS

When a prototype of a system has been produced, it can be useful to evaluate it against a set of requirements. Derelov (2009) highlights that evaluation is an important aspect of the design process and this can take place as the system is being developed or at a later stage when there is a partial working prototype available. The aim of the evaluation is usually to determine aspects of the system which meet the user requirements. The initial prototype used in the evaluation can be a paper prototype whilst that used at a later stage would likely have more features and functionalities provided. Bonnardel and Sumner (1996) highlight that evaluation plays a major role in design because each successive evaluation step guides the course of design activity. Maguire (2001) highlights that evaluating a prototype against user requirements is a very important activity within the system development life cycle; it can confirm how far the user and organizational objectives have been met as well as provide further information

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[21] http://en.wikipedia.org/wiki/Prototype

for refining the design. It is often advisable to carry out evaluation at an early stage of the design process before changes become expensive to avoid having to make significant changes when the design process reaches a later stage. This can help to reduce the overall design costs.

Maguire (2001) highlights two main reasons for usability evaluation; to improve the product as part of the development process (by identifying and fixing usability problems): “formative testing” and to find out whether people can use the product successfully: “summative testing”. Pekkala (2012) also mentions that formative and summative evaluations are useful and often employed in the design process. The formative evaluation is aimed at improving the usability of an interface when the system is developed or revised (Nielsen, 1993). Furthermore, it is aimed at validating or ensuring that the goals are being achieved and to make improvements, if necessary by means of identification and subsequent remediation of problematic aspects (Weston et al., 1995). The formative evaluation can help designers identify problems during design and use them to improve the end product. Methods which can be used for formative evaluation include heuristic evaluation, participatory evaluation, satisfaction questionnaires and interviews (Pekkala, 2012; Nielsen, 1993, Maguire, 2001).

For the summative evaluation, this process is often conducted after the system is designed and is used to determine whether it meets the intended purpose. Scriven (1967) highlighted that this type of evaluation is used to assess whether the results of the system being evaluated met the stated goals. Saettler (1990) also suggests that summative evaluation is undertaken to test the validity of a theory or impact of a practice (e.g. with a system) so that future efforts may be improved or modified. Maguire (2001) highlights that summative evaluation may be used to obtain metric data where tasks can be simulated and users observed e.g. in controlled tests. The observer would try to avoid interacting with the user except guiding the evaluation session.

A range of methods which are used in evaluating system are discussed as follows and they start from the more formative methods which are usually employed in the early stages of system development through to the more formal summative evaluation methods which are employed as the system prototype evolves to later stages.

Participatory evaluation

In participatory evaluation, the users employ a prototype whilst engaging with a number of scenarios. Zukoski and Luluquisen (2002) highlight that participatory evaluation is a partnership approach to evaluation in which stakeholders actively engage in developing the evaluation and all phases of implementation. This can be done in a session where they come together and interact with the system to identify any issues to be addressed. Maguire (2001) highlights that during the session people explain what they are doing by talking or "thinking aloud" and the information is recorded on tape or captured by an observer. Monk et al. (1993) also suggest that they are asked questions based on what they are doing and what they expect to do so that the information can be used as feedback for the development process. The process needs to be planned carefully in order to resolve any conflicts which may arise from differences in opinions from users. This would ensure that a desirable outcome is obtained from the session.

Maguire (2001) highlights two variations of participatory evaluation; an evaluation workshop and evaluation walkthrough. In the evaluation workshop, users and developers would come together and users would interact with the system to perform a range of tasks which have been set out by the designers. The designers would observe the users during the tasks and can later explore the issues which were identified through a facilitated discussion. Fitter (1991) suggests that one of the strengths of the technique is that it brings users and developers together in a facilitated environment and multi-user involvement would draw out several perspectives on a particular design issue. The evaluation walkthrough is a process of going step-by-step through a system design and getting reactions from users (Maguire, 2001). The process can be facilitated by a stakeholder and one or more users would provide comments as the evaluation walkthrough proceeds. Maulsby et al. (1993) and Nielsen (1993) suggest that problems are listed in this stage and they should be reviewed and changes proposed to the design elements.

Heuristic evaluation

Heuristic or expert evaluation is a technique where one or more usability and task experts will review a system prototype and identify potential problems that users may face when using it (Maguire, 2001). The technique was developed by Jakob Nielsen (see Nielsen, 1993). The technique involves having a small set of evaluators examine a system and judge its compliance with recognized usability principles ("the heuristics"). The main goal of heuristics evaluation is to identify any problems associated with the design of user interfaces[22]. Maguire (2001)

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[22] http://en.wikipedia.org/wiki/Heuristic_evaluation

highlights that it is necessary to have more than one expert involved in the process to avoid any bias during the evaluation. In heuristic evaluation, the expert begins by understanding the user characteristics, the nature of the task and the working environment. There can be a discussion with the design team and also user representatives to obtain this understanding. In the process, there can be questions asked which can highlight issues so that recommendations can be made to improve the design. Maguire (2001) highlights that the advantage of an expert appraisal is that it is a very quick and easy way to obtain feedback and recommendations. However, disadvantages such as the expert having some bias towards specific design features and the expert not being able to assume the role of a normal user may exist. Nielsen (1992) and Shneiderman (1998) provide several heuristics which can prompt the evaluator and provide a structure for reporting design problems.

Satisfaction Questionnaires

Questionnaires are a well-established technique used for eliciting, recording and collecting information from end users (Irune, 2009). Users are provided with a series of questions for which they are expected to provide relevant answers. Subjective impressions formed by users based on their experiences with a deployed system or new prototype can be collected using this technique (Maguire, 2001). Questionnaires may be administered in paper and ink or a computerized version may be used. They can be used to obtain subjective data from users of a test system before and/or after a study. Questionnaires can enable collection of quantitative data which are based on numerical ratings for specific variables e.g. ratings from 1-10 which are based on a user experience. Questionnaires can be used on their own or in conjunction with other evaluation methods to clarify or deepen understanding (Preece et al., 2002). When used in conjunction with other methods (e.g. real road or simulator studies) users are requested to complete the questionnaire before and/or after the studies depending on specific aims. When used as a method on their own, they can potentially gather information about users' experience with certain interfaces or systems (Irune, 2009). In most cases, the participants are presented with tasks to perform using a system and thereafter they are presented with the questionnaire for completion. Once the questionnaire has been completed, the data is analyzed and interpreted by HCI practitioners or qualified and experienced psychometricians.

Questionnaires have several advantages, for example, they give feedback from the point of view of the user. They are quick and cost effective to administer and the data which is obtained through this method can be used as a reliable basis to compare or demonstrate that quantitative targets in usability have been achieved (Irune, 2009). Also, they are cheap and easy to design and enable collection of data from a wide range of users. Furthermore, they are similar to interviews in the sense that they can have closed or open questions (Irune, 2009). There is extra care usually put into the design of questionnaires to ensure that the questions asked are well worded and that data can be obtained and analyzed efficiently. There are several disadvantages to this method however. The first is that because responses which are provided by participants in the questionnaires are subjective, they only indicate the user's reaction to a situation from their perspective (Irune, 2009; Maguire, 2001). Therefore, it is possible that there would be questions which relate to time measurement or the frequency of event occurrence which may not be reliably answered in the questionnaires. Secondly, the questionnaires are designed to fit a number of different situations (because of the costs involved) and may not stress in detail particular issues that exist with a particular system (Irune, 2009). Therefore, it may be difficult to obtain useful feedback due to the open-ended nature of some of the questionnaires which are based on the user's perceptions. This can often make the analysis of such data even more difficult.

There are several designs of questionnaires. Doll et al., (1988) were one of the early users of questionnaires to assess users' views on a system. They reported a measure of end user computing satisfaction by obtaining a ten-item measure of the users' reactions to a specific computer interface. Dr John Brooke designed a questionnaire which was circulated via email to assess user satisfaction. The scale of the questionnaire was called the System Usability Scale (SUS). Kirakowski (1987) highlights that both Doll et al. and SUS questionnaires were interesting because they signified one of the first attempts to capture a user's attitudes to a single interface. Lewis (1991) developed a three-item questionnaire which was called the After Scenario Questionnaire (ASQ) and it is normally used immediately after completing specific tasks in scenario-based usability studies. The ASQ was found to be reliable even though the psychometric properties were only estimated for a small number of users. The three questions of ASQ measure underlying aspects of user's perceptions which include the ease and speed of completing the scenarios as well as the contributions of support information to carrying out the tasks.

Also work was begun in the Human Factors Research Group (HFRG) in University College York in 1986 on specific questionnaire methods of analyzing user reactions. A similar approach adopted by Doll et al. (1988) was used by the

HFRG in York. This was mainly to examine the reactions of users to a specific computer product which they had used before. The Computer User Satisfaction Inventory (CUSI) (Kirakowski, 1987; Kirakowski and Corbett, 1988) was the first result obtained from the HFRG studies. This was a short questionnaire of 22 items which had two subscales of usability called the "at the time effect" (i.e. the degree to which users liked the computer system) and "competence" (the degree to which the users felt supported by the computer system). These subscales were arrived at through cluster analysis of intercorrelations of responses to individual questions in a large initial item pool (Irune, 2009). The pool was obtained from literature searching and discussion with end-users on their reactions to how they performed their normal tasks when using their usual systems. The range of systems sampled was large and heterogeneous.

Other questionnaires which have been developed for usability studies include the Software Usability Measurement Inventory (SUMI), NASA Task Load Index (TLX) and Usefulness Satisfaction and Ease of use (USE) questionnaires. The SUMI questionnaires were developed in the late 1990 where the HFRG were entrusted to develop a questionnaire method which could be used to assess the usability of a system. This was part of the collaborative ESPRIT project MUSiC (Metrics for Usability Standards in Computing). They were given the task of examining the CUSI competence scale, expand it and extract further subscales to achieve an international standardization database for the new questionnaire. They were also required to validate its use in commercial environments. The objectives were met at the end of the project. In 1993, the SUMI questionnaire was first published and has been used since. The questionnaire is mentioned in the ISO 9241 as a method which is recognized for assessing user satisfaction when using different systems.

The NASA Task Load Index is a standardized questionnaire which is used to measure cognitive workload and mental effort required to perform a task subjectively (Irune, 2009). This NASA TLX was later adapted by and named the DALI (Driving Activity Load Index). It contains subjective ratings on six subscales; physical demand, mental demand, temporary demand, frustration, effort, and performance. Pauzie and Pachiaudi (1997) mention that in association with other behavioral criteria, this method allowed them to assess the usability of different types of guidance and navigation systems and mobile phones. There are three dimensions (utility, easiness and satisfaction) and four domains (hardware software, documentation and services) which the USE questionnaire measures.

Interviews

Abras et al. (2004) highlight that interviews can enable designers to evaluate the user’s likes and dislikes about a design and to gain a deeper understanding of any problems. Maguire (2001) highlights that interviews are a very quick and inexpensive way to obtain subjective feedback from users based on their practical experience of a system or product. This form of evaluation allows a system to be examined and user satisfaction data to be obtained along with any problems relating to the features or functionality which would need to be revised. Preece et al. (1994) suggest that interviews can be used to obtain subjective data based on a system which is currently being examined or can be used after a session involving interaction with a new system. Maguire (2001) highlights that the interviewer should base his/her questions on a pre-specified list of times while allowing the user freedom to express additional views that they feel are important. This can provide the user with a sense of not being forced to give a specific response which may be contrary to his/her opinion.

Interviews can be formal where a set of pre-defined questions are asked in order to obtain a particular response or they can be informal where the user has the flexibility to provide an answer which best suits them. In some cases, it can be a mixture of both. Interviewers should be able to structure their interviews to obtain adequate response from users.

Controlled testing

Usability evaluation can often involve setting up trials where representative users would be invited to perform a specific set of tasks with a system being developed. The setting for such trials can be in the field (natural setting of task) or a controlled laboratory setting. According to Maguire (2001), the aim of such trials is to gather information about users' performance with the system, their comments as they operate it, their post-test reactions and the evaluator's observations. Field studies take place in the natural setting of the task and presents real life context of use. There is little control for the experimenter and participants cannot be deliberately exposed to dangerous situations (Kircher, 2007). However, due to the real nature of the setting, it is likely to increase the risk of harm or danger to participants in the event of an unwanted circumstance. For driving studies, the field studies can be on a real road test or a test track.

A controlled laboratory setting on the other hand, allows a system to be tested under conditions which are close to those that will exist when it is used for real.

The laboratory setting supports the simulation method which is considered to be one of the optimal methods which can be used to acquire knowledge of the user's behavior. Kircher (2007) suggests that studies which involve simulation are carried out in a mock-up environment and Young et al. (2003) highlights that it is a safe method for conducting driving research. For driving studies, a driving simulator is used. The driving simulators were initially developed during World War II and are used to study driver behavior and interaction with the vehicle and road environment (Roberts, 1980; Blana, 1996). The main application areas for driving simulator studies in recent years have been to investigate acceptability issues of innovative transport elements (e.g. road design, in-vehicle devices), to evaluate the safety concept (e.g. possible increase of accidents due to new road design, in-vehicle devices) and the credibility and transferability of the simulator results to the real world (Blana, 1996).

Driving simulators provide a range of benefits for the study of driving behavior and performance in research. They allow the experiment conditions to be controlled when compared with the real world studies which limit what the experimenter would be able to control whilst evaluating a system e.g. weather, illumination, road conditions, traffic etc. Reed and Green (1999) mentioned that this greater experimental control allows the type and difficulty of tasks to be precisely specified and potentially confounding variables can be eliminated. Hence, a wide range of variables can be measured without actually waiting for them to happen since the experimenter has control over the occurrence of such variables. Kircher (2007) outlines that the laboratory simulation method is advantageous for conducting driving studies because such studies can be conducted in the controlled environments where the situations which are desired by the experimenter can be presented and all the participants can be subjected to the same conditions.

The use of driving simulators is also considered to be a safe method for conducting research. Blana (1996) highlights that driving simulators in controlled settings are able to provide an inherently safe environment for driving research which can be easily and economically configured to investigate a variety of human factor research problems. Kircher (2007) and Goodman (1997) also highlighted that it is possible to study dangerous situations using this method which is not possible on the road due to ethical reasons. This means that there is limited risk of injury or harm to the participants because they are isolated from the conditions which can affect their safety.

In addition to being safe and providing control, this method is considered to be cost effective and efficient for conducting evaluation of systems. Daza et al. (2011) highlight that driving simulators are cost-effective and efficient because the cost which would be involved in modifying the cockpit of a driving simulator to address a particular issue would likely be less compared to what would be required to modify an actual vehicle and also ensure that such modifications meet required standard. Rosson and Carroll (2002) suggest that this approach can be small in scope and scale and can focus on particular tasks, features and user consequences. This can make them easy to manage.

Despite these benefits, there are other factors which affect the use of the controlled testing method for system evaluation. The first relates to simulator validity which is a key aspect of simulator design. Mudd (1968) defines validity as “the way in which the simulator reproduces a behavioral environment”.

Young et al. (2003) indicate that there are two key aspects of simulator validity; simulator fidelity and behavioral validity. Simulator fidelity is concerned with how the physical correspondence of a simulator relates to that of its real world counterpart. Godley et al. (2001) and Triggs (1996) suggest that the closer a simulator approximates the real-world driving environment in terms of design and layout of its controls, the realism of the visual scene and its physical response characteristics, the greater the fidelity the simulator would have. For example, a simulator which offers realistic visual scene and layouts e.g. trees and road signs would have a greater fidelity when compared with one which offers black and white representations of the roadway having only major road markings. Also, a fixed base simulator would have less fidelity when compared with a motion base simulator because of the movement of the vehicle which is present in real world driving.

Bach et al. (2009) outline three levels of fidelity for driving simulators. These are the low, mid and high fidelity. Low fidelity simulators offer the least realistic driving environments and controls. They usually have a fixed base and lack motion. They are often simple in design e.g. a computer and chair. This means that they can be cheap and easy to configure. They usually lack high external validity because it is difficult to generalize the findings based on limitations of the setup (Bach et al., 2009). Mid fidelity simulators offer better features when compared with low fidelity simulators based on the controls and graphics. They usually have a fixed base and lack motion like the low fidelity simulators but are usually more expensive to assemble. They have a higher external validity when compared with the low fidelity simulators based on the better features they provide (Bach et al., 2009). High fidelity simulators offer realistic driving environments, components and layouts. They are motion based and can simulate the kinaesthetic and motion cues which are present in the real world (Bach et al., 2009). However, they can be expensive to design because of the different features which are integrated in their design. The high fidelity simulators have a high external validity because they produce near-real life contexts. This can help participants to interact with them in a similar way to real world driving.

Blaauw (1982) indicates that behavioral validity is concerned with the way in which the driver behaves in the simulator and in actual vehicles. Participants are usually aware that they are being watched in a controlled environment because of the setup which can have an effect on their driving behavior and performance. Participants may restrict themselves from displaying any unusual behavior in front of the experimenter so that they are not judged as bad drivers. Blaauw (1982) suggests that the best method for determining a simulator's behavioral validity is to compare the driving performance in the simulator to the driving performance in a real vehicle using the same driving tasks. This would ensure that the similarities in behaviors can be established when a comparison is done.

Fors et al. (2013) and Godley et al. (2001) outline two levels of behavioral validity; the absolute and relative validity. They suggested that the absolute validity is achieved when the absolute values of a particular effect is equal in the simulator and actual vehicles. The relative validity on the other hand is achieved when the direction or relative size of an effect is the same in the simulator and reality. It has been found that most driving simulators have good relative behavioral validity for many driving performance measures although absolute validity is not well demonstrated (Blaauw, 1982; Carsten et al., 1997; Godley et al., 2001; Reed & Green, 1999).

Apart from the absolute and relative validity there are issues of internal and external validity according to Fors et al. (2013). They suggest that they are not specifically related to simulator studies but are relevant in most kind of research. According to (Kaptein, et al. 1996), a research method has internal validity if there are no alternative explanations for an obtained effect. They suggest that internal validity is often better in simulations when compared in reality with regards to control to external factors e.g. (surrounding traffic, weather, etc.). They also described external validity as the extent which the results obtained in a specific study can be generalized (Kaptein et al., 1996). Fors et al. (2013) suggest that external validity refers to whether the results from the simulator can be generalized to real driving. When considering the simulator validity, these aspects are important aspects to take into account.

Due to differences in techniques and resources, it can be difficult to reproduce simulators which are identical (e.g. based on procedures, tasks and measures). Irune (2009) suggests that in the design of a simulator, validity must consider the driving task itself because the driving task is usually complex and a specific simulator configuration would only enable investigation of a subset of behaviors which are involved in carrying out this complex task. It is important to consider variables to be measured when designing a simulator because the data which would be collected can have an impact on the simulator validity.

Another issue which affects the use of simulators in controlled testing is motion sickness. Driving simulators can present the issue of motion sickness to participants where they may be exposed to headaches, nausea or dizziness in the simulator. Nichols and Patel (2002) highlight that there is ongoing research into the theoretical basis for this phenomenon. Kennedy et al. (2001) outline that experimenters can use practical guidance (e.g. through questionnaires) to identify and eliminate individuals who may experience sickness in the driving simulator. This can reduce problems during the studies where a study may be stopped to cater to a participant who has been affected. Also, Burnett (2008) outlines counter-measures which can be implemented in the driving simulator setup (e.g. air-conditioning, high consistent frame rate, natural back lightning) in order to reduce the prevalence of motion sickness.

Furthermore, due to safety concerns, simulation-based studies can be time-restricted in order to ensure that participants are not exposed to the simulated environment for too long as it can cause them to be stressed or tired. It is not well established the reasonable amount of time which participants should be exposed to the simulation before it becomes unsafe for them. Future research can look into this matter. Kircher (2007) suggests that the restriction may have an impact on whether only the novel aspect of a system is investigated or whether the same behavior would be observed in a long term study. This may pose some problems for experimenters in actually obtaining “true distraction” behaviors in a driving simulator environment. Kircher (2007) then concludes that as a result of the time restriction, secondary tasks are usually presented as distractors to participants even though it is not clear if the “secondary task performance” is different from “performance while distracted”.

The procedure for conducting simulator-based studies is that the participants are screened for their susceptibility to simulator sickness and those who fail to meet the specified criteria are not allowed to take part for safety reasons. Those who meet the criteria would be presented with the information on what to do and how to use the driving simulator. A test vehicle would be used which can be fitted with a system being tested and the simulator software would collect data on the behavior and performance of the participants.

In summary, the review of the human-centred design process outlined the range of methods which are available for the design of systems. Each of the methods which can be used in the process are particularly useful at different stages of development. It would now be useful to understand how some of these methods were applied in this research to design and evaluate the virtual car head-up display. As a result, the next section provides information regarding the virtual car head-up display design process and the criteria which were used to select methods to be used.

3.3 THE VIRTUAL CAR HEAD-UP DISPLAY DEVELOPMENT PROCESS

The virtual car head-up display development process is in line with the human-centred development process as the driver is the focus of the design. It follows the same development process from the beginning (planning the development process) to the end (evaluating the design solution). However, when compared with the human-centred development process which is outlined in ISO 13407, the virtual car head-up display development process includes one more process at the end. This involves evaluating the prototype of the virtual car against existing counterparts in order to ascertain usability, behavioral adaptation and performance measurement. The virtual car head-up display development process is presented in Figure 3.2 below which highlights how the virtual car head-up display development evolved during the design.

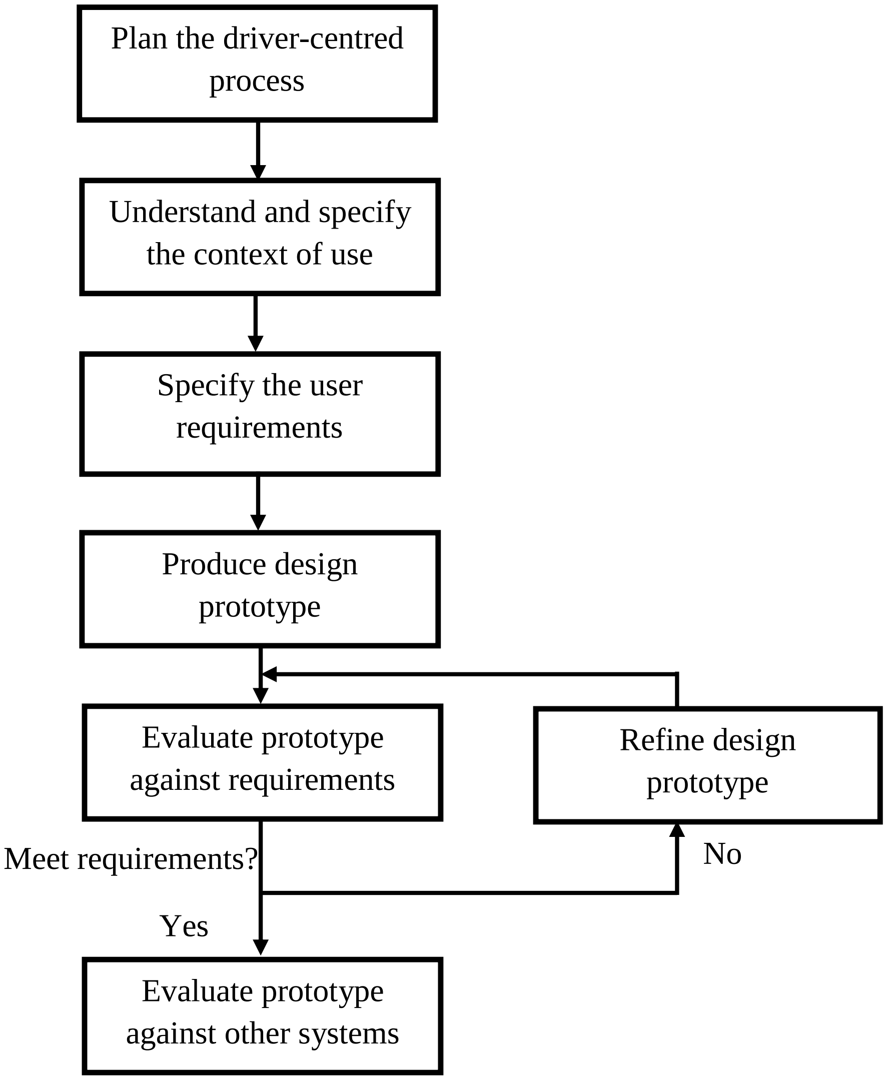


Figure 3.2: The development process for the virtual car head-up display

The methods which were used in each of the processes are discussed as follows.

3.3.1 PLAN THE DRIVER-CENTRED PROCESS

When planning the driver-centred process, this was done carefully to ensure that the process of developing the navigation interface would be successful. Usability planning and scoping was done with a number of stakeholders e.g. usability experts, drivers and designers. The aim of the planning process was to ensure that the stakeholders contributed their expertise in developing the virtual car head-up display so that the eventual design would be usable. Answers to several issues of concern were identified to create a clear vision for how usability can support the development objectives. For example, the reason for the design (to provide an alternative interface to existing navigation interfaces which would be associated with less workload and risk of distraction), the overall objectives (to improve safety and navigation performance), how the system will work (user enters destination into system database, virtual car appears in driver's field of view and follows a route which driver should take), the key functionalities needed by drivers (indicating instruction and vehicle turning), the eventual users of the system (drivers) and social, physical and technical factors which may affect the use of the system (road traffic, weather, illumination, driver attributes e.g. visual capacity, age, gender, personalization etc.) were answered during this phase of the development process.

3.3.2 UNDERSTAND AND SPECIFY CONTEXT OF USE

The context in which the virtual car head-up display would be used was studied to gain an understanding of the issues which would affect its use. There were several methods used in this process including identifying stakeholders, context of use analysis, field studies/observation and task analysis. The stakeholders who would be affected by the use of the virtual car head-up display were identified and were noted to be drivers, even though it is not well understood if other people e.g. vehicle passengers or pedestrians could be affected by its use. The context-of-use analysis was done by analyzing the physical, social and technical environment within which the virtual car head-up display would be used e.g. weather, road conditions and illumination. It was identified that the virtual car has to be visible for the driver to see within changing lighting conditions. Also, the layout of junctions and roundabouts were identified in order to identify how to design the vehicle turning instruction.

The field study/observation was conducted to observe how drivers performed the navigation task to ensure that the virtual car head-up display would meet their needs. Details of the field study/observation which was done in the research are outlined in Appendix C of this thesis. Finally, the task analysis was done to understand the driving and navigation tasks in order to design adequately for them. The task analysis revealed that there should be consideration given to how drivers respond to traffic e.g. following other vehicles ahead so that this could be factored into the virtual car behaviour. Also, the navigation task was analyzed to identify aspects which affect navigation performance e.g. taking correct turns. There was also the issue of when the navigation instructions e.g. indicating and turning, should be issued in the navigation task which was analyzed to ensure that drivers understand what needs to be done when an instruction is provided.

3.3.3 SPECIFY THE USER REQUIREMENTS

Specifying the user requirements involved specifying properties of the virtual car head-up display like the size, behavior, looks, quality and components to ensure that drivers would be able to use the virtual car head-up display without having much issues. The user requirements which were specified for the virtual car head-up display are outlined in chapter 4 “configuring the attributes of the virtual car head-up display”. Also, there were benchmarks from the field study conducted which could be used to compare the design of the virtual car head-up display. Finally, the properties of the virtual car head-up display were specified in such a way that would fit with safety regulations e.g. being visible enough and not too large such that it would not cause drivers to struggle with its use and as a result affect their focus on execution of the primary driving tasks.

3.3.4 PRODUCE DESIGN PROTOTYPE

A prototype for the virtual car head-up display was produced in the driving simulator based on the specification which were outlined in the previous stage. The methods which were used in the design of the prototype for the virtual car head-up display were the computer animation and Wizard of Oz. For the computer animation, a series of screens were developed using snapshots of the virtual car from different angles. The screens were placed in a slideshow and controlled using buttons in order to choose which screen would appear to support a particular action e.g. turning left, going forward or indicating right. The Wizard of Oz approach was adopted in the research so that drivers would not notice that the virtual car was controlled by the experimenter. The behavior of the virtual car would be determined by the experimenter at different points during the drive, for example, the virtual car would turn right on approaching a turn to be made to the right. The prototype for the virtual car head-up display also included a test vehicle in the laboratory setting where the virtual car would be projected. The test vehicle was mocked up using a table, chair and controls.

3.3.5 EVALUATE PROTOTYPE AGAINST REQUIREMENTS

In order to ascertain usability, performance and behavioral adaptation of drivers with the virtual car head-up display, it was necessary to evaluate the design against the requirements. There were several criteria which were outlined for the selection of a suitable method which would be used during the evaluation process. These included the following.

- Provide a safe and convenient environment for evaluating the navigation system: The selected method should allow drivers to carry out the evaluation process in a safe and convenient environment in order to significantly reduce the risk of harm or injury to the drivers. Also, there should be a reasonable control over the experiment conditions.
- Be cost-effective: The selected method should be cost-effective so that it would be easy to implement and configure the evaluation setup.
- Support reproducible test conditions: The selected method should make it possible to reproduce the test conditions so that all the drivers would be examined under similar circumstances.
- Ensure simple and efficient data gathering: The selected method should ensure that the data gathering process is simple and efficient so that results can be easily deduced.
- Be suitable for use at various stages of the development process: The selected method should be suitable for evaluating the navigation system at various stages of the development process so that different aspects of the navigation system can be examined e.g. feasibility, conformity and comparison with existing system.

Based on these criteria, the laboratory driving simulator-based approach was selected because it was considered safe with less risk of harm or injury to the drivers. A pilot study in the driving simulator was conducted to determine the feasibility of the concept i.e. whether drivers would be able to follow the instructions issued by the virtual car head-up display with less workload and risk of distraction. Several studies were also conducted to collect data which would be used to judge the perceived level of acceptance of the new technology. A representative driver sample was recruited to take part in participatory evaluation of the virtual car head-up display. Interviews and questionnaires were used to gain insight into the experiences of the drivers during the drives (see Appendices A, B, and D). The information obtained highlighted issues which needed to be looked at in further detail. As a result, the initial studies were considered to be part of the design process.

The iterative process was employed in the development of the virtual car head-up display during the initial evaluation studies. As various aspects of the head-up display were examined, it was necessary to evolve the design concept where necessary to improve the design or ascertain which of the examined aspects best suits the virtual car head-up display. Therefore, the process of refining the virtual car head-up display design was done when there were issues which were identified to be addressed.

3.3.6 EVALUATE PROTOTYPE AGAINST OTHER SYSTEMS

For research purposes, the virtual car head-up display design was evaluated against a number of other navigation systems. This was done to determine how the virtual car head-up display compared against its existing counterparts based on its usability, performance and behavioral adaptation. There were computer animations developed for each of the navigation interfaces which were examined and they were fitted within a mocked-up device. The device was then installed in the test vehicle when the respective navigation interface was to be evaluated. The evaluation process took place in the controlled test setting where desirable variables were measured. A decision was made on which variables would be useful for this evaluation process and it was identified that variables including speed, lateral lane position, headway, task times and response to events would be measured. Several authors suggest that these variables are good indicators for when drivers are likely experiencing increase in workload and distraction (Young et al., 2003; Kircher, 2007; Green, 1998; Dingus et al., 1995; Tijerina, 1998; Srinivasan and Jovanis, 1977; Gartner et al., 2002)

In this evaluation process, there was an additional task which was added to infer workload and risk of distraction. This task was the peripheral detection task (PDT). The peripheral detection task (PDT) is a secondary workload measure developed by Van Winsum et al. in 1999 to measure driver mental workload and visual distraction. The task measures hit rate and reaction times to visual stimuli (Engström et al., 2005). The method has been used in a number of studies to examine visual and cognitive attention (Harms and Patten, 2001; Jahn et al., 2005; Martens and van Winsum, 2000). In the task, a driver is presented with spots of lights randomly and is required to acknowledge the detection of the lights using a specific medium. Olsson and Burns (2000) suggest that as the drivers become more distracted by the primary task, they respond slower and fail to detect more peripheral detection task targets. This occurs because more attention would be shifted towards execution of the primary tasks when compared with detection of the peripheral targets.

The peripheral detection task approach is based on studies which were conducted by Miura (1986) and Williams (1985, 1995). Findings from the studies indicate that when the primary driving task demand is increased due to the driver interacting with an in-vehicle system the driver will get tunneled in to the in-vehicle system thereby causing a slow reaction to or entire missing of the peripheral targets. The driver's vision becomes narrowed to the region of the in-vehicle system such that the regions outside of the in-vehicle system become ignored. The peripheral detection task is easy to describe and perform thus makes it easy to use in a range of driving settings. There are several variations that exist in the implementation of the task but in general there are spots of light displayed at different horizontal angles on the windshield (Martens and Van Winsum, 2000). Also, other type of objects can be used as the stimulus in the task. The stimulus is usually present for a short period of time and drivers acknowledge the presence of the stimulus by using an available mechanism.

The peripheral detection task has been criticized for being an additional task which the drivers have to perform (Kircher, 2007). Performing the peripheral detection task increases the driver's attentional demand on the peripheral object and can potentially affect the driver's concentration on the primary driving tasks. Kircher (2007) argues that there may be adverse impacts on the driver's performance during the peripheral detection task as the workload of the driver is increased. Furthermore, Dirkin and Hancock (1985) suggest that the narrow field of view in the peripheral detection task is claimed to be attentional rather than perceptual. This implies that information in the field of view can be perceived but attention is only allocated to certain bits of importance. Thus, there is a selective process for dealing with information received.

Also, it is not particularly clear how performance in other tasks is affected when performing the peripheral detection task. For example, there may be a situation where another manual task has to be carried out which involves interference in using one's hand for the task and pressing a button to acknowledge the peripheral stimulus i.e. when another task has to be carried out at the same time as the peripheral detection task. Kircher (2007) also highlights that there may be an issue if the driver is left or right-handed because in-vehicle systems which are placed in the middle console are operated with a specific hand and the acknowledgement mechanism is often mounted on the dominant hand. Hence, it is possible that a participant can use the wrong finger to press a button when carrying out the peripheral detection task and another concurrent task. This may be of interest if there is importance placed on the use of the fingers while performing the tasks.

The PDT was selected to be used in the evaluation process because of its sensitivity to changes in workload and distraction. This was identified as a useful variable to induce in the evaluation process to determine the extent of behavioral adaptation which would occur with each of the navigation systems examined.

3.4 SUMMARY

The human-centred approach offers a useful set of methods and procedures which can be used in the design of systems which would be usable and acceptable to users. This research adopted the approach as the focus of the design was on the drivers who are the main stakeholders and eventual users of the system. The review focused on understanding the development process so that this could be tailored to design the virtual car head-up display. The design process which was employed for the virtual car head-up display was discussed along with the methods which were selected based on the criteria which were outlined. It was suggested that some of the methods would be used alone whilst others would be used in conjunction with other methods e.g. the laboratory simulator-based method would be used in conjunction with questionnaires and interviews in order to gain better insight into the experiences of the drivers. It was outlined that variables including speed, lane position, headway, task times and response to events would be measured to meet the needs of the research. It is anticipated that this review was able to provide an understanding of the process which was undertaken in the development of the virtual car head-up display. Having outlined the methods which would be used to develop the virtual car head-up display, the next chapter focuses on understanding the virtual car head-up display concept and how the attributes were configured in the design process.

CHAPTER

4

THE VIRTUAL CAR HEAD-UP DISPLAY

4.1 INTRODUCTION

The previous chapter provided a review of the methods which were used in the design and evaluation of the virtual car head-up display. This chapter begins to highlight the design of the virtual car head-up display. The rationale for the design of the virtual car head-up display is first outlined after which a detailed explanation of the virtual car head-up display is provided. The evolution of the design process is outlined after which the various considerations taken into account during the design process are outlined. Finally, a number of hypothetical benefits of the virtual car head-up display for drivers are outlined. It is anticipated that this chapter would provide a good understanding of what the virtual car head-up display can offer drivers during navigation.

4.2 RATIONALE FOR DESIGN OF THE VIRTUAL CAR HEAD-UP DISPLAY

With advancements in technology, current systems available to drivers can be enhanced. In the navigation context, there can be improvements to current systems available to drivers so that their tasks can be carried out with greater efficiency and performance. Opportunities exist for the enhancement of vehicle satellite navigation systems. Also, issues which have been outlined in the literature with head-up displays can be addressed in order to improve performance in the driving task. The issue of driver distraction and its impact on the driving task makes it even more important that future systems are designed with care to reduce any unwanted outcome.

From the literature review, it was pointed out that when drivers are faced with an increased workload because they are concurrently interacting with an in-vehicle system e.g. a vehicle satellite navigation system, the driver is often translating instructions provided from the system to situationally meaningful actions before eventually executing them out on the road. The work involved during the translation can be visual (looking between interfaces), auditory (listening to information) or cognitive (processing information). For example, drivers are instructed using voice commands from vehicle satellite navigation systems which tell them what to do while navigating e.g. after 100 yards turn right. The driver receives this navigation instruction but it is possible that the driver may not really know what to do with it. The driver would know that after 100 yards a right turn would be made. But that may be all that the driver can tell at that point in time. The driver may wonder what other actions might be involved in executing this instruction which needs to be attended to. Questions such as "should there be indicating?", "is the vehicle in the right lane?" or "where is right for the driver in relation to the vehicle satellite navigation system?" may all be going through the driver's mind. It would be helpful if the driver is able to focus on performing the primary driving tasks rather than worry about these other questions especially in a complex task as driving. It is therefore based on such concerns that the virtual car head-up display is designed.

The virtual car head-up display aims to address these concerns by displaying the navigation instructions to drivers in a way that reduces this work of translation so that drivers focus less of their attention on the virtual car head-up display and its instructions and instead on the performance of the primary driving tasks. Therefore, rather than process abstract navigation instructions, the driver would see the required actions to be executed being displayed on the windshield by the virtual car so that all that they do is replicate those actions based on their real world driving competence. This can help to reduce their workload and risk of distraction from the road.

Furthermore, the location of the navigation systems within the vehicle has been found to have some effects on the behavior and performance of drivers. Several studies have examined head-up and head-down displays and they found that head-up displays are more suitable for presenting information to drivers (Ververs and Wickens, 1998; Tönnis et al., 2005; Charissis et al., 2008; Liu and Wen, 2004). A head-up display allows the driver to attend to the forward road simultaneously whilst also taking in driving information. However, authors such as Ward and Parkes (1994) and Crawford and Neal (2006) highlight two main issues which are misaccommodation and attention capture with head-up displays and the impacts they can have on the driving task. The virtual car head-up display is an attempt to mitigate these issues so that there is better performance of the driving tasks.

4.3 THE VIRTUAL CAR HEAD-UP DISPLAY CONCEPT

The virtual car head-up display concept is owned by the author and supervisors of this thesis. The virtual car head-up display is designed to be a visual-sound, turn-by-turn navigation system whose navigation instructions are embedded in real world navigation practices (e.g. following other vehicles, indicating and turning; see Figure 4.1). This is aimed at aligning the navigation instructions with the primary tasks of driving so that they are easy to understand and execute.

Figure 4.1: The virtual car indicating and turning views

The design concept aligns the virtual car navigation instructions with the ways which real world vehicles behave (e.g. the virtual car indicates, turns, enters or exits lanes etc.). This is aimed at allowing drivers to draw on their familiarity with the instruction sets so that they can recall the instructions from memory based on real world navigation competence rather than process the navigation instructions from scratch. This can make the virtual car head-up display easy to use. Furthermore, by aligning the navigation instructions from the virtual car head-up display with the primary tasks of driving, its use would not conflict with the performance of the primary driving tasks instead it would support their performance. For example, the virtual car is designed to indicate and turn at junctions to inform the driver of the route. The driver should easily understand that a turn is to be made when the indicating light of the virtual car comes on and the virtual car turns on arrival at the junction. When the indicating light comes on, the driver is reminded to indicate and it is expected that the driver would immediately respond. Thus, the driver would display the safe actions required to make a turn as the use of the indicator is a safe practice required to inform other road users of the driver’s intent on the road.

Also, the cognitive workload of the driver to process the visual and sound instructions from the virtual car would be reduced because of the reduced complexity of the instructions. The driver only sees and replicates the visual actions and easily understands the indicating sound from the virtual car. This suggests that the virtual car head-up display would be a visual interface which has little cognitive impacts. The indicating sound instruction is not very complex therefore it is expected that there would be less demand for the attention resources for processing this input modality. This can be linked to the multiple resource theory where there are different resources which are used for processing different input modalities and the demand for these resources affects performance in the tasks. Hence, by reducing the attention resources which are required to process the navigation instructions the driver can allocate more attention resources instead to performing other concurrent driving tasks.

The virtual car would be displayed on the windshield so that it is overlaid on the road scene where the driver’s attention is. The virtual car would appear as a lead vehicle in the driver’s field of view so that the driver would appear to follow the virtual car. This would enable the accommodation of the virtual car and the field of view to be easy for the driver because both information sources would exist in the same visual space. In the driver’s field of view, the virtual car would be conformed to the road scene so that the instructions are tailored at the exact points in the real world (see Figure 4.2). This can enable better performance of the driving tasks.

Figure 4.2: The virtual car head-up display in driver’s field of view

When the virtual car is displayed in the driver’s field of view, this would help to reduce the visual diversion of attention from the road scene when scanning for navigation information. This can help to enhance the driver’s performance in several tasks such as hazard perception, lane positioning during navigation, collision avoidance and response times to critical events in the road scene. This is in line with suggestions in the literature about the benefits of head-up displays in the driving task (Liu and Wen, 2004; Charissis et al. 2008; Ververs and Wickens, 1998). As a result, this can have positive safety impacts on the performance of the driving task.

Furthermore, the virtual car is designed to be a turn-by-turn navigation system so that the risk of attention capture which is associated with the navigation interface is reduced. The essence of reducing the attention capture with the virtual car head-up display is to enable the driver allocate more time and attention to the performance of the primary driving tasks rather than focusing attention on the actions of the virtual car. As a result, the virtual car is designed to have two states and would be in one of these states at any given point in time. These states are the active and inactive states. The active state is the state which is used to indicate to the driver that a turn instruction should be executed i.e. turn/indicate left/right. On approaching a junction to turn, the virtual car would begin to indicate in the direction of the turn. This would prompt the driver to prepare to make the turn when they see the indicating light come on. On arrival at the turn, the virtual car would simulate the turn action for the driver to replicate. The inactive state on the other hand, is the state where the driver is informed that no turn actions need to be made. In this state, the virtual car would remain in a forward idle position so that it indicates to the driver to keep going straight. This would indicate that only a forward movement should be made. The purpose of the inactive state is to reduce the need for the driver to focus attention continuously on the virtual car and instead focus on performing the primary driving tasks e.g. monitoring the road scene for hazards. The inactive state is the state between two active states.

In essence, the virtual car head-up display is targeted to reduce the additional workload and risk of distraction when drivers are issued with navigation instructions while driving. The visual workload of the driver would be reduced by augmenting the virtual car with the road scene to reduce visual shift of attention when scanning for navigation information. This can reduce the eyes-off-the-road time for the driver. The virtual car integrates an inactive state which can help to reduce the demand on the driver to continuously monitor the navigation interface. This would allow the driver to focus more time and attention on performing other visual tasks. Also, the cognitive workload of the driver would be reduced by providing the navigation instructions in a way that is part of the primary driving tasks and easily understandable by the driver. This would reduce the translation work involved in understanding the instructions and as a result less time would be spent on processing the navigation instructions. This can reduce the mind-off-the-road time for the driver.

4.4 EVOLUTION OF THE VIRTUAL CAR HEAD-UP DISPLAY CONCEPT

The literature suggests that there is growing interest in the design of head-up displays as they hold significant benefits for presenting drivers with navigation information. To find a solution to the issues of workload and distraction with current navigation systems, it seemed a possible approach to design a navigation interface which provides navigation information using every day driving practices. The idea of the virtual car head-up display is not based upon any practical or theoretical evidence and therefore it is necessary to shape this idea into one which would align with the way navigation instructions are provided in the real world. This would help to make the virtual car a more usable and acceptable system when it is fully implemented in the real world. It would therefore be useful to understand the contexts within which the virtual car head-up display would be used. To achieve this, the field study approach was adopted because it would enable the designer to be physically located within the context of use and observe the actions to account for in the design process of the virtual car head-up display.

4.4.1 FIELD STUDY INVOLVING LEAD VEHICLE FOLLOWING TASK

The field study which is mentioned in this section highlights two drivers (John and Allen) who drive to a football stadium from Allen’s house by following a route which is known only to John, the lead driver. Allen the trailing driver looks at John’s vehicle while following him and replicates his actions whilst they drive from his house to the stadium. The full study is contained in the Appendix section (Appendix C) of this thesis and only a few instances of the study are referred to in this section.

Summary of field study

John and Allen want to go to a football stadium to watch a game and John knows the route which leads from Allen's house to the football stadium and backwards. John decides to follow the routes when Allen asks him to lead the way. This means that John's vehicle would appear in Allen's field of view during the outward and inward journeys. The outward journey goes from Allen's house to the football stadium and the inward journey goes in the reverse direction. During both journeys, Allen executes the visual actions which are displayed by John's vehicle. (Note: Allen wanted to remain anonymous, so he is not recorded in the video). The sequence of actions during the journeys is outlined as follows:

Outward journey

John turns left into new road and accelerates.

Allen drives behind John and turns left into new road.

John turns on his indicator, slows down and stops at cross junction while waiting to spot gap in oncoming traffic going to the left.

Figure 4.3: John waiting at the junction

Allen sees John indicate, slow down and stop at the junction. He turns on his indicator, slows down and stops behind John.

John spots a gap in traffic and enters it turning left into the new road.

Allen arrives at junction but stops due to oncoming traffic. He watches oncoming traffic to spot gap in traffic.

Allen spots a gap in traffic and turns left into the new road.

Allen accelerates and catches up with John.

John slows down on approaching a cross junction with a red traffic light. His brake light goes on.

Allen sees John’s brake light go on at the red traffic light and slows down as well.

John stops on reaching the red traffic light on the left hand lane besides another car.

Figure 4.4: Stopping at red traffic light

Allen stops in the same lane behind John.

Both drivers wait at the junction. Allen watches the traffic light and anticipates when it would turn green to resume the journey.

The traffic light turns green and the drivers resume driving.

Both drivers are in a bus lane and want to change to the vehicle lane. Other vehicles are on the vehicle lane.

Figure 4.5: Driving in bus lane

John turns on his indicator which signaled.

Figure 4.6: John indicating to change lanes

Allen sees John indicating to the right and also turns on his indicator to the right.

John spots a gap in the traffic on the vehicle lane and enters the gap in between the vehicles.

Allen looks into his right side mirror for oncoming traffic and spots a gap in traffic. He switches lane as well.

John stays in the right hand lane of a three lane road.

Allen keeps on driving behind John and stays in the right hand lane of the road.

John turns on his indicator signaling to the right at another roundabout.

Figure 4.7: John indicating at roundabout

Allen turns on his indicator as well and follows John along the roundabout. He looks left for oncoming traffic.

John enters the middle lane of the road and accelerates. It is the ring road heading south.

Figure 4.8: John positions vehicle in middle lane of road

John stays in the lane going straight as a vehicle ahead of him enters a side road.

Figure 4.9: John stays in lane going straight

Allen sees John stay in the lane and keeps following him. Both drivers keep driving along.

John stays in the lane going over the bridge as other vehicles exit the lane via a slip road to the left.

Figure 4.10: John going over a bridge

Allen turns on his windshield wiper as the rain gently starts to fall.

A vehicle enters the road from a slip road on the left.

Figure 4.11: Vehicle entering from slip road

John and Allen are in the middle lane of a three lane road and John turns on his indicator signaling to the left to switch lanes.

Figure 4.12: John indicates and changes lanes

Allen sees John turn on his indicator and enter the left hand lane of the road. He turns on his indicator, looks into his left side mirror for oncoming traffic and enters the left lane of the road.

A vehicle from the right hand lane of the road enters the gap in between John and Allen.

Figure 4.13: Vehicle enters in between both drivers

Allen cannot see John but tries to maintain the gap between his vehicle and the unknown vehicle to avoid further increasing the gap between him and John.

John leaves the main road via a slip road on the left.

Allen sees John’s vehicle enter the slip road and follows it.

Figure 4.14: John leaves main road via slip road

John slows down on approaching a roundabout. His brake light goes on as he slows down.

Figure 4.15: John waits at a junction

Allen slows down behind the vehicle ahead.

John drives off after spotting a gap in oncoming traffic and takes the first exit.

Allen reaches the roundabout and spots a gap in the traffic which he enters and accelerates. He also takes the first exit. He accelerates and catches up with John.

John slows down on approaching a red traffic light and stops.

Allen sees John’s vehicle stop and he stops behind John.

Figure 4.16: John stops at a red traffic light

Both drivers wait and anticipate when the traffic light would turn green.

The traffic light turns green and both drivers resume driving.

A vehicle on the left hand lane of the road indicates to the right and enters the gap in between John and Allen as the lane on the left is closed.

Figure 4.17: Vehicle entering in between both drivers

The vehicle in between John and Allen switches to the left lane of the road.

Figure 4.18: Vehicle leaving gap between both drivers

John stops at the set of red traffic lights.

Figure 4.19: John stops at red traffic lights

Allen stops behind John at the set of red traffic lights. Vehicles on the left and right of the cross junction begin moving. John and Allen wait for the traffic light to turn green.

The traffic light turns green and John resumes driving. Allen resumes driving and follows John.

John turns on his indicating light to the left as he approaches a junction to turn left.

Figure 4.20: John indicating to the left

Allen also turns on his indicator which signals to the left.

John leaves the main road via a slip road on the left.

Figure 4.21: John leaves road via slip road on the left

Allen follows John and leaves the main road via the slip road.

John slows down and indicates to the left at a junction. John turns left at the junction and drives along.

Figure 4.22: John indicates and turns left at a junction

Allen also slows down and turns left on approaching the junction.

John slows down and indicates to the right at a junction.

Figure 4.23: John indicates to the right at a junction

Allen also turns on his indicator signaling to the right.

John slows down and stops on arriving at the destination.

Allen stops behind John.

Inward journey

Both drivers commence the return journey back to Allen's house.

John drives off and indicates to the right on approaching a junction.

Figure 4.24: John indicates to the right at a junction

Allen slows down on approaching the junction and turns on his indicator to the right.

John stops on arriving at the junction and waits to spot gap in oncoming traffic on both sides of the main road.

John spots a gap and enters the gap. He accelerates and drives along.

Allen stops on arrival at the junction. He waits and watches to spot a gap in oncoming traffic on both sides of the main road.

Allen spots a gap and enters the gap. He accelerates and drives along.

John stops on the right hand lane of the road at a red traffic light ahead.

Figure 4.25: John positions his vehicle in the lane turning right

Allen slows down and stops behind John at the red traffic light. Both drivers wait at a junction for the light to turn green.

The traffic light turns green, both drivers resume driving.

John turns right at the traffic light.

Figure 4.26: John turns right at the junction

Allen follows John but slowly turns right as a bus ahead also turns at the junction.

Allen accelerates and catches up with John.

John enters the middle lane of the road.

Figure 4.27: John enters the middle lane of the road

Allen sees John enter the middle lane of the road. He looks into his left side mirror for oncoming traffic and enters the middle lane of the road.

John slows down, turns on his indicator signaling to the left and enters the middle lane of the road as traffic builds up ahead on the right hand lane of the road.

Figure 4.28: John indicates and enters the middle lane of the road

Allen sees John's indicate and enter the middle lane of the road. He also turns on his indicating light signaling to the left, looks in his left side mirror and enters the middle lane of the road.

John slows down and stops on arriving at a red traffic light as a pedestrian crosses the road.

Figure 4.29: John stops at red traffic light

Allen sees John's vehicle slow down and stop at the red traffic light. He slows down and stops at the red traffic light behind John.

The traffic light turns green and both drivers resume driving.

John enters the right hand lane of the road and keeps driving.

Figure 4.30: John stays in right hand lane of the road

Allen sees John enter the right hand lane of the road. He looks into his right side mirror for oncoming traffic and follows John.

John positions his vehicle in the right hand lane of the road on approaching a junction. He slows down and stops as there is a red traffic light at the junction.

Figure 4.31: John positions his vehicle in right hand lane of the road

Allen enters the right hand lane of the road. He slows down and stops behind John at the red traffic light. Vehicles on the main road ahead are moving in both directions. A pedestrian ahead crosses the road.

Figure 4.32: John stops at junction with red traffic light

The traffic light turns green and John resumes driving. He accelerates and drives along going straight at the cross junction.

Allen sees the traffic light turn green and John resume driving. He accelerates and follows John.

John stops on arriving at another junction with a red traffic light.

Figure 4.33: John stops and indicates at red traffic light

Allen turns on his indicating light signaling to the left and slows down before stopping behind John on arriving at the junction. Vehicles on the main road at the cross junction are moving in either directions. Both drivers wait and anticipate when the traffic light would turn green.

The traffic light turns green and John resumes driving. He turns left at the junction.

Figure 4.34: John turns left at junction

Allen sees John turn left at the junction. He turns left at the junction and follows John.

John enters the middle lane and keeps driving.

Figure 4.35: John in middle lane of road

Allen sees John enter the middle lane and follows him.

John stays on the right hand lane of the road at a Y-junction.

Allen stays behind John.

John turns right at a junction ahead.

Allen sees that John has turned right and turns on his indicator signaling to the right. He waits and watches for oncoming traffic in the opposite direction and spots a gap in the traffic. He enters the gap and turns right at the junction.

John turns his indicator on signaling to the right at a cross junction and turns right on arriving at the junction.

Figure 4.36: John indicates and turns right at junction

Allen sees John turn right. He turns on his indicator light signaling to the right and follows John.

John slows down and in front of Allen’s house.

Figure 4.37: Both drivers arrive back at Allen's house

Allen slows down and stops behind John in front of his house and the journey ends.

Several learning outcomes were identified from the field study above which are described as follows:

- Design for context: The field study highlighted the contexts within which the virtual car head-up display would likely be used e.g. weather, traffic, road conditions etc. It allowed the observation of how these factors occur in the real world so that they could be accounted for in the design of the virtual car head-up display. This would help to ensure that the attributes of the virtual car head-up display are well configured so that it would be easy to distinguish the virtual car from other objects in the driver's field of view. Also, it would help to ensure that the virtual car is designed to fit within the contexts which have been identified.
- Outline of design requirements for virtual car: The looks, behaviours and size of the lead vehicle in the field study provided guidance on how to shape the design of the virtual car. For example, the indicating action was

seen as a vital action for informing the following driver when a turn instruction would be executed. As a result, it was decided that this action would be integrated in the virtual car design. Also, the turn instruction was seen as vital for informing the driver of the arrival at a turn and therefore it was decided that this would be integrated in the actions of the virtual car. The size of the lead vehicle was such that it did not obstruct the driver’s view of other road objects and therefore allowed detection of critical events in the road scene. The virtual car was therefore designed with this in mind.

- Availability of a baseline for comparing usability of the virtual car design: The actions of the lead vehicle provided a set of actions against which the actions of the virtual car could be compared for its usability in the navigation context. This could be helpful in identifying the external validity of the virtual car head-up display design.

The field study highlighted two scenarios in the design of the virtual car head-up display. These are the problem and design scenarios. According to Rosson and Carroll (2002), a problem scenario is a story about the problem domain as it exists prior to technology introduction. They describe the design scenario on the other hand as how the problem scenario can be addressed using a particular method. In the next section, there is a problem scenario and a design scenario which are outlined.

4.4.2 THE SCENARIOS

Problem scenario

Mark and his wife Emelia are new in the city and would like to go to the cinema later in the day to see a new movie release. Unfortunately Mark does not know how to get to the cinema on his own. Mark's work colleague James and his wife Anna drive in their car to the cinema and Mark and Emelia drive in their car behind. Two days later, Mark wants to watch a league match at Nottingham Forest football club. However, James is away on a business trip. Mark would like to follow a car to the football stadium in the same way that he followed James' car.

Design scenario

A virtual navigation car is displayed on the windshield of Mark's vehicle so that it appears as though it is out on the road. Mark can then follow this virtual car in the same way that he followed James' car two days earlier.

4.5 CONFIGURING THE ATTRIBUTES OF THE VIRTUAL CAR IN A PROTOTYPE

Having obtained a set of design requirements for the virtual car head-up display, the design of the virtual car head-up display prototype would now begin. The configuration of the design attributes for the virtual car head-up display was done in Microsoft PowerPoint and the attributes which were configured are as follows:

Looks

To support optimal interaction with the virtual car for the drivers it was considered vital that the looks of the virtual car be carefully selected. The question which was asked at this stage was therefore “how should the virtual car look?” There were two looks considered in the design process. These were cartoon car and real car looks. The cartoon car did not look like a real car and there were concerns over the suitability of this look in supporting driving actions. For the initial testing, it was also difficult to simulate the turn actions with the cartoon car and as a result this option was not selected. The real car option was therefore selected as the preferred look in the design process and a 3D model of a 2007 Toyota Camry was selected. The rear view of the virtual car which the driver would follow while navigating is shown in Figure 4.38.

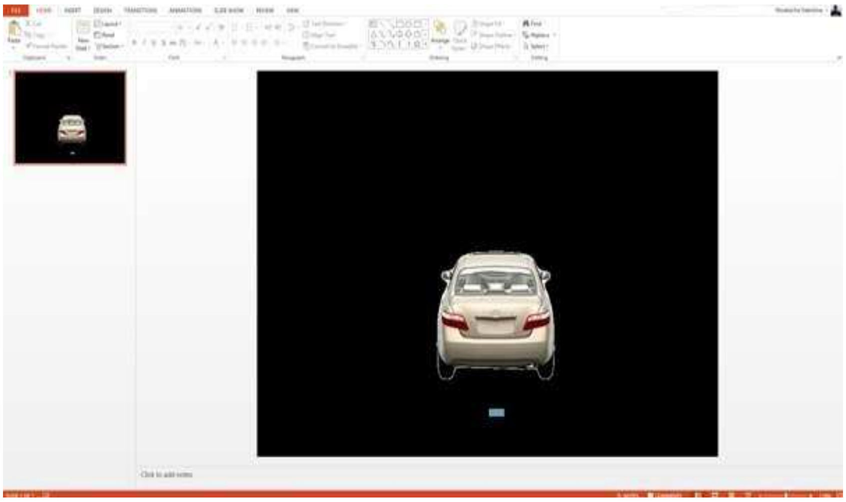


Figure 4.38: The look for the virtual car

Behavior

The next aspect of the virtual car which was configured was its behavior. In fact, this was considered to be the most important design aspect of the virtual car head-up display in terms of its usability. There were considerations given to whether the virtual car should indicate, turn and remain idle on the windshield. The indicating instruction was considered useful for notifying the drivers of the intended direction of turns thereby enhancing their spatial orientation. In the field study, it was seen as a vital part of the instruction set which was used to inform the driver as to when a turn was approached. Hence, the left and right indicating instructions were integrated into the virtual car behavior. A button was added to the slides which would be used to initiate a turn action for the virtual car e.g. turn left button would be pressed to initiate the turn left action, turn right button to initiate the turn right action and a button to return the virtual car to the forward position. These are shown in Figures 4.39 and 4.40.

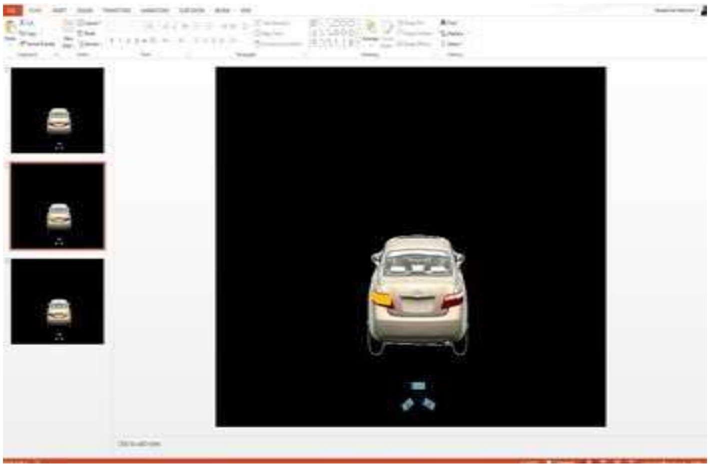


Figure 4.39: Configuring virtual car left turn

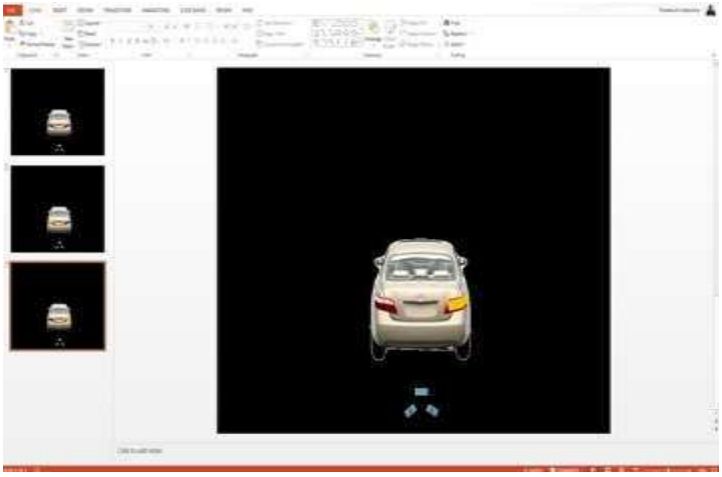


Figure 4.40: Configuring virtual car right turn

The turn instruction was also considered important because it was vital to notify drivers of their arrival at a turn location and to support lane switching. It was thought that integrating this feature would enhance navigation decision making and performance with the virtual car head-up display. The field study showed that when the lead vehicle turned at a junction, the driver behind followed. Therefore the turn action was integrated into the virtual car behavior. The turn action was achieved by taking a snapshot of the 3D car at different angles which corresponded to when it was turning left and right. Also, there were buttons added to the slides which would be used to initiate the turn actions for the virtual car. These are shown in Figures 4.41 and 4.42.

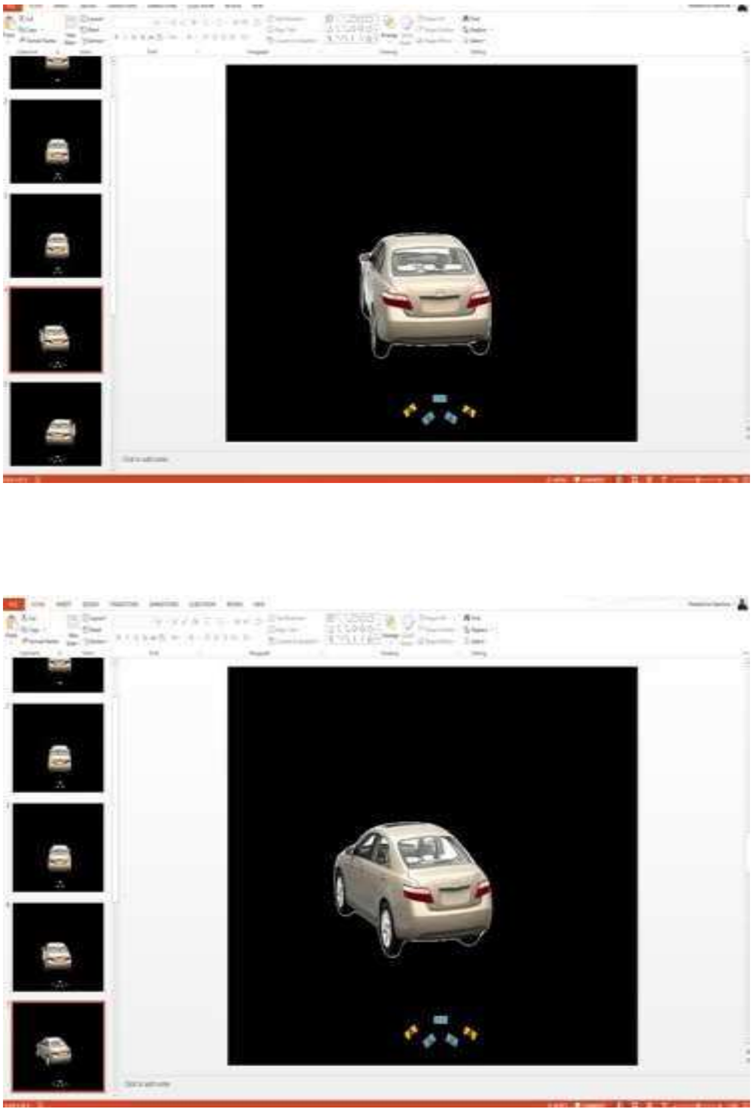


Figure 4.41: The virtual car turning left

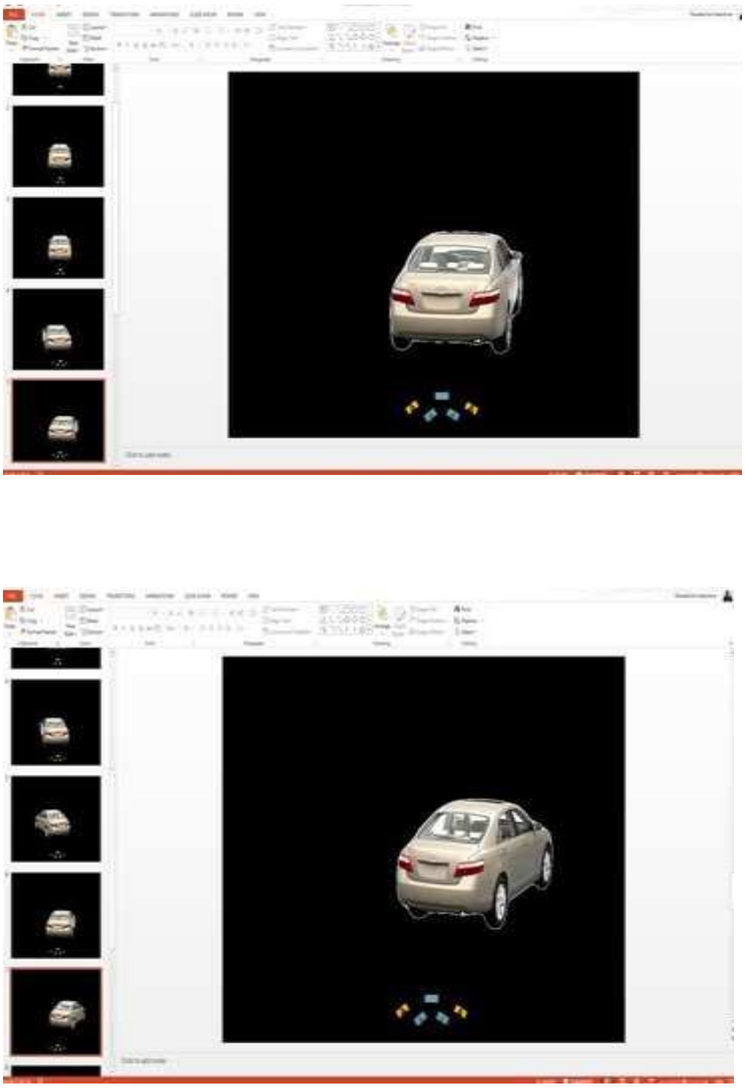
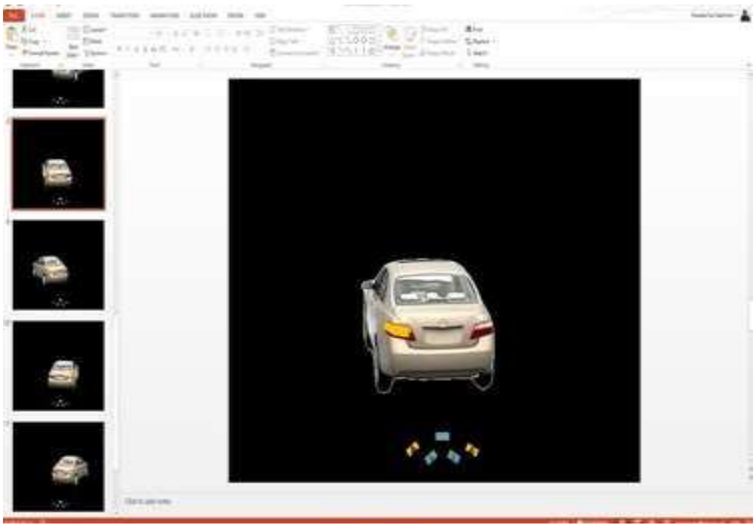


Figure 4.42: The virtual car turning right

It was important that there was a clear distinction between the turn instruction and the lane changing instruction because both instruction sets employ similar mechanisms. To determine that a lane changing instruction is provided, the maximum angle of the virtual car would be 45 degrees. However, for a turn at a junction, this would be 90 degrees. This can eliminate confusion surrounding the instruction provided which involves turning.

Furthermore, it was important to have a combination of the indicating and turn actions in the virtual car to support realistic turn scenarios which were evident in the field study. This was therefore configured as shown in Figure 4.43 and 4.44.



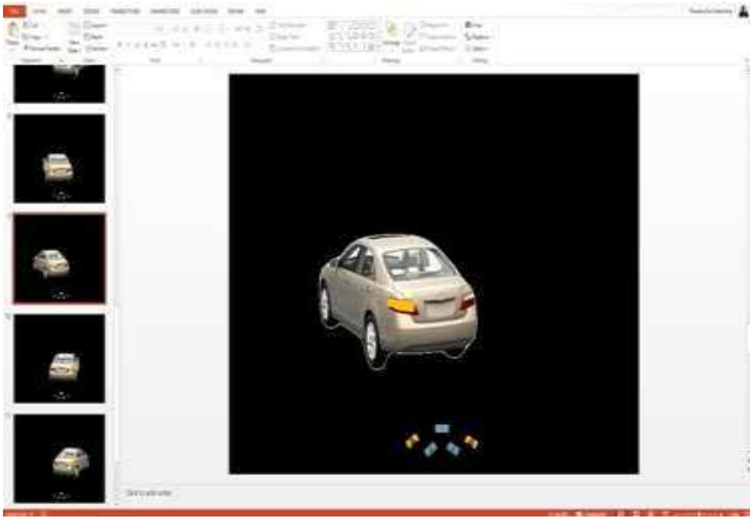


Figure 4.43: The virtual car turning left and indicating

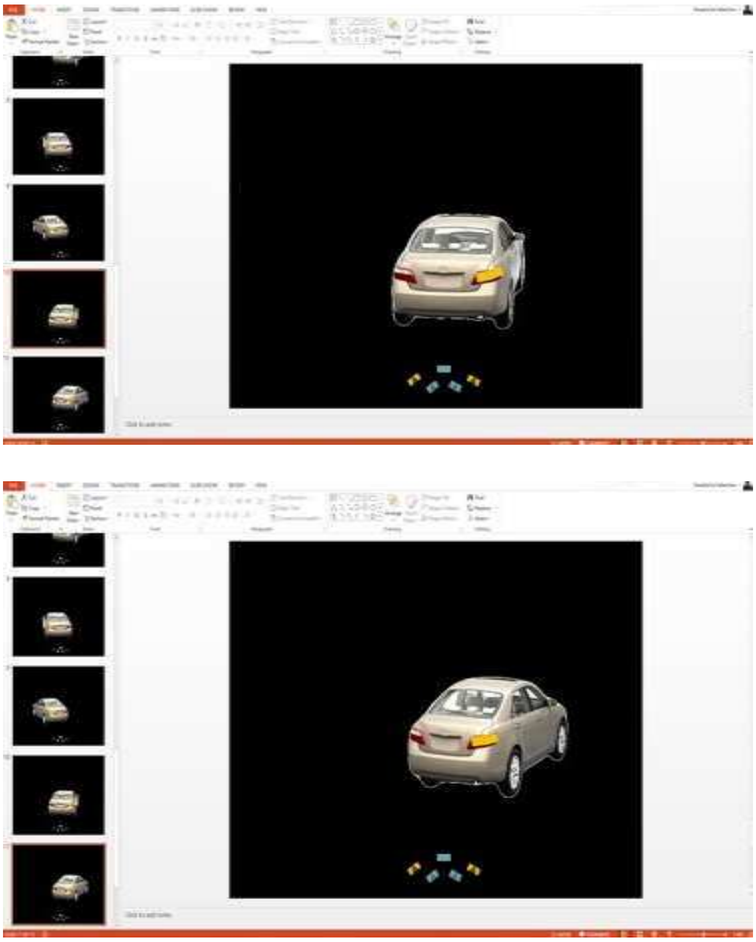


Figure 4.44: The virtual car turning right and indicating

Finally, to reduce the impact of attention capture with the virtual car head-up display, it was considered vital to integrate an inactive state where the virtual car would be idle. This would help to reduce the need for the driver to focus attention on the virtual car so that attention could instead be focused on performing the primary driving tasks. Therefore, for the initial testing, the rear view of the virtual car shown in Figure 4.38 (which also indicates a forward movement) was used to indicate the inactive state.

Size

The next aspect of the virtual car which was configured was the size. It was important to obtain a good size for the virtual car so that the driver can easily see the instructions which are issued without obstructing the view of the road scene. The size of the virtual car was varied in the simulator in order to fit it within the lane and not be too big or small. Sizes tried included 5x5 cm, 10x10 cm and 7x7 cm. The 7x7 cm size for the virtual car was chosen for the initial design as it provided the best size for the virtual car which was visible to the driver and which fitted best within the lane. This is shown in Figure 4.45.

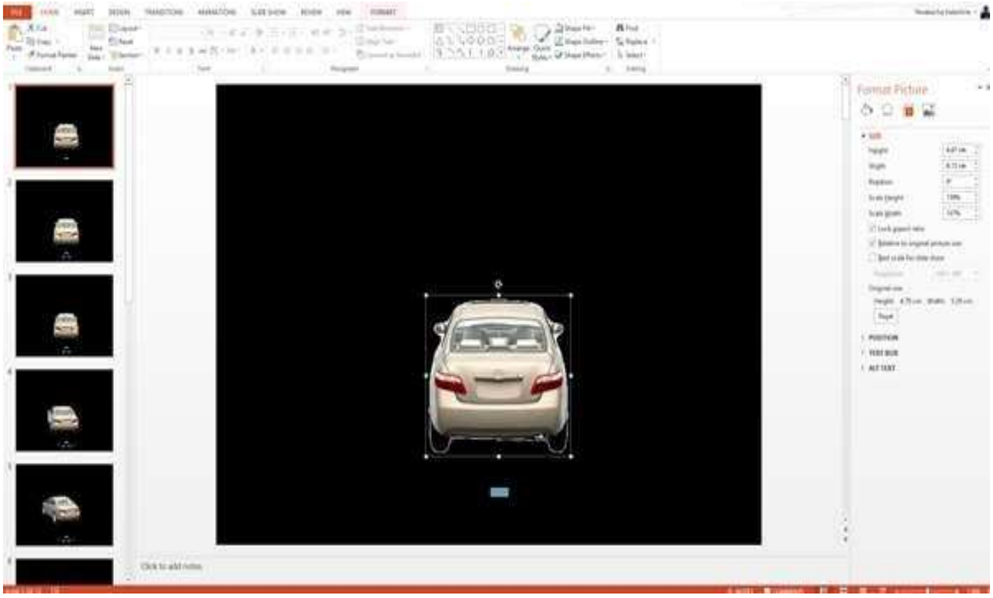


Figure 4.45: Selecting the best size for the virtual car head-up display

Another aspect which was configured to ensure it was easily seen by the drivers was the size of the indicating lights. It was found during the design of the virtual car that displaying the indicating lights to fit within the normal area of the car allocated to them made it difficult for the driver to see the indicating direction. The original size of the indicating lights was 0.2x0.2 cm. They had to be enlarged to 1.2x1.2 cm to be clearly seen by the driver in the simulator. These are shown in Figure 4.46.

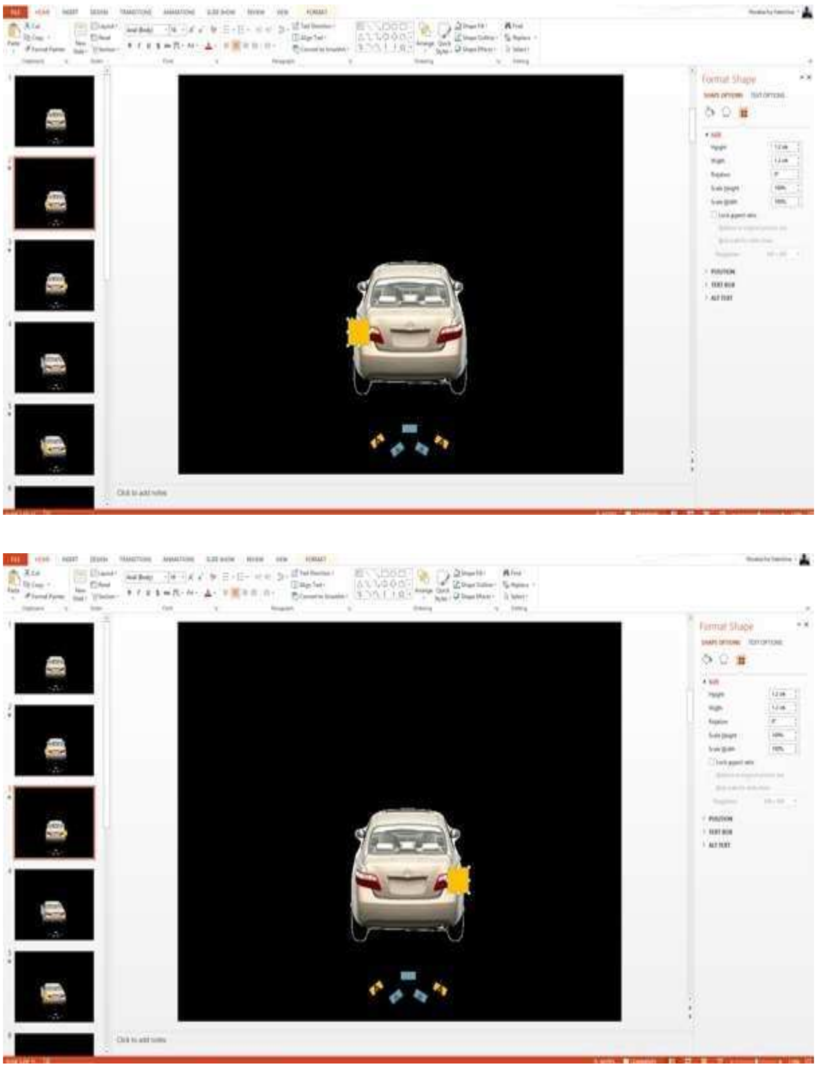


Figure 4.46: Enlarged left and right indicating lights

Quality

The final aspect of the virtual car which was configured was its quality. Two settings for the quality of the virtual car were configured in the driving simulator. These are the brightness and sharpness. However, it was identified that the need to adjust these two settings would depend on illumination in the simulator room. As a result, they were left to be adjustable.

4.6 EQUIPPING THE TEST VEHICLE WITH THE VIRTUAL CAR PROTOTYPE

The simulation of the virtual car prototype was then displayed on a computer screen which was fitted in the test vehicle of the driving simulator. The screen for the virtual car display was placed on the dashboard at an angle of 45° below the windshield to provide a reflection of the virtual car in the driver's field of view. The projection of the virtual car was positioned to appear in the middle of the road in the simulated environment. This is shown in Figure 4.47.

Figure 4.47: The virtual car prototype in the simulator

4.7 COMPONENTS OF THE VIRTUAL CAR HEAD-UP DISPLAY

The components for the virtual car head-up display are divided into two categories; hardware and software components. The hardware components include:

- The windshield: This is the interface upon which the virtual car would be displayed.
- An adjustable projection display/lens: This would be used to project the virtual car unto the windshield. An adjustable projection device would

be used in order to ensure that drivers can optimize positioning to suit their physical attributes e.g. height and visual capacity.

- A keypad and visual display unit: The keypad would be used to enter the destination address into the system. The visual display unit would display the information which is entered into the system by the driver.
- A set of speakers with adjustable controls: The speakers would be used to highlight the indicating sound made by the virtual car to notify the driver of the turn instruction. The volume of the sound would be adjustable so that the driver can adjust it under varying noise conditions.

The software components include:

- The virtual car head-up display software: This software would be used to control the virtual car head-up display program. Microsoft PowerPoint was used during the design and testing phases in this research. During the eventual implementation of the virtual car head-up display in real vehicles, it would be the manufacturer’s decision on which software to use to control the program for the virtual car head-up display.
- A system database: The system database would contain information about the different routes, settings and preferences for the virtual car.

4.8 HYPOTHETICAL BENEFITS OF THE VIRTUAL CAR HEAD-UP DISPLAY

The virtual car head-up display is designed to be an alternative navigation system to those existing which can improve driving behavior and performance. There are several hypothetical benefits which are initially outlined for drivers when they use the virtual car head-up display during navigation. These include the following:

Enhanced visual detection of events in the surrounding environment

With the virtual car displayed on the windshield, it is anticipated that drivers would not need to look away from the road to view navigation information. Also, it is anticipated that the inactive state of the virtual car head-up display can reduce the need for drivers to continuously monitor the virtual car whilst driving. This should allow the drivers to spend more time attending to the primary tasks instead of the virtual car head-up display. It is expected that this would enhance the driver's detection of events in the surrounding environment.

Reduced reaction times to critical events in the surrounding environment

With the enhanced detection of events in the surrounding environment, it is expected that this would enable drivers to react faster to those events when they occur. This is because when the drivers are able to easily detect events in their field of view, they can have enough time to react to the events and avoid unwanted outcomes.

Enhanced navigation performance

It is expected that when the virtual car displays the visual navigation instructions e.g. turning and indicating, this would provide the driver with a good understanding of what needs to be done. Therefore it is expected that this would improve the decision making process during navigation e.g. when taking turns. This can reduce the navigation error rates of drivers and thus, improve navigation performance which would lead to more efficient journeys.

Reduced information processing times

The indicating and turn mechanisms which are used by the virtual car to instruct drivers are predicted to require less processing times when compared with mechanisms used by existing navigation systems e.g. voice commands and visual maps. Drivers would not be required to do any significant work of translation with the virtual car because the instruction sets are based on actions in the primary driving task. Hence, this can reduce the amount of time which is spent on attending to the virtual car head-up display in comparison to the road scene.

Transferability of knowledge for instructions in different contexts

The same instruction mechanisms would be used by the virtual car in different contexts which would make it easy for the drivers to transfer their knowledge of the required actions to the different contexts.

Fits with the real world driving context thus increasing likeability

The virtual car head-up display has been designed to provide drivers with required navigation instructions using techniques which fit with the real world driving context. This can increase the understanding and usability of the virtual car head-up display which in turn can ensure that the virtual car head-up display is liked better than existing navigation systems.

4.9 NEXT STEPS

The next step in developing the virtual car head-up display would be to test the hypothetical statements which have been made with regards to the benefits of the navigation interface for drivers. This would involve usability evaluations for the virtual car head-up display in several simulator-based studies in order to explore different aspects of the navigation system e.g. feasibility, conformity and comparison of driver behavior and performance against prototypes of existing navigation systems. These would be useful to provide evidence which supports the benefits of the virtual car head-up display in the navigation context. Also, the comparison would be useful to identify the benefits which the virtual car head-up display has over its existing navigation system counterparts.

4.10 SUMMARY

This chapter provided details about the virtual car head-up display concept including a rationale and description for the concept and how it was shaped through a field study. The configuration process of the virtual car head-up display was outlined and the prototype was fitted in a test vehicle. A number of hypothetical benefits for the virtual car head-up display were outlined for drivers when the virtual car would be used during navigation. These would be examined in usability evaluation studies which are outlined in the next few chapters of this thesis. The findings from such studies should provide some understanding of the issues which surround the use of the virtual car head-up display. Also, they should be able to indicate whether the virtual car head-up display can achieve the purpose of its design which is to provide navigation instructions to drivers in a way which involves less workload and risk of distraction when compared with existing navigation systems.

CHAPTER

5

A FEASIBILITY STUDY OF THE VIRTUAL CAR HEAD-UP DISPLAY CONCEPT: A PILOT STUDY

5.1 INTRODUCTION

In the previous chapter, the concept of the virtual car head-up display was introduced. It was stated that the virtual car head-up display is targeted towards reducing the driver’s workload and risk of distraction whilst being easy to use. This would be achieved by presenting drivers with navigation instructions in their field of view which resonate with the primary driving tasks and those which they are familiar with. This would reduce any shift of attention from the road scene and work of translation. For example, rather than having to process voice commands and/or a visual map, the driver would see the visual actions in the field of view and hear the indicating sound of the virtual car. The driver would simply be required to replicate the instructions which are provided.

Having introduced this design concept of the virtual car head-up display, it is important to conduct usability evaluations to understand how its use affects the driver’s performance of the primary driving tasks. Furthermore, initial usability evaluations can provide valuable feedback from users which can help improve the eventual design of the system. Carroll and Rosson (1985) indicate that the goal of usability evaluation is to provide feedback in software development, supporting an iterative development process. As a result, this chapter focuses on presenting a pilot study which examines the feasibility of the design concept and evaluates whether the virtual car head-up display can be used as a navigation tool. It further seeks to highlight any usability issues which may be experienced by the drivers to identify areas for improvement of the design concept. Feedback from the drivers which relate to their experience during the drives would be considered in order to improve the design of the virtual car head-up display where necessary.

5.2 THE AIMS OF THE STUDY

The feasibility study aims to determine whether the virtual car head-up display concept is intelligible and can be used by drivers during navigation. Furthermore, it aims to highlight any usability issues which the drivers would experience in order that the design of the virtual car head-up display would be improved upon.

5.3 THE SETUP

The feasibility study was conducted in a controlled laboratory setting where an improvised test vehicle which comprised of hardware and software components was used.

Hardware components

This comprised of an interconnected game steering wheel controller and pedals which were used to control the movement of the vehicle on the simulated environment road. There was a piece of glass perspex which was used as the windshield upon which the virtual car head-up display was displayed. A chair and table were used for the driver's seat and dashboard. A 23" monitor was used to project the virtual car head-up display on the glass perspex. In addition to the test vehicle hardware, a projector was located at the rear of the simulation room which displayed the simulated environment on a plain background in front of the drivers. The hardware setup is shown in Figure 5.1.

Figure 5.1: Simulator hardware setup

Software components

This comprised of the STISIM (Systems Technology Incorporated Simulator) software which was used to simulate the driving environment. There was also the Microsoft PowerPoint software which was used to design the simulation of the virtual car head-up display prototype.

5.4 THE PARTICIPANTS

There were five male drivers who took part in the feasibility study. They were all residents in Nottingham and were aged between 19 and 32 years (average age was 27.2 years). The selection of the drivers was based on eligibility in certain criteria. They were each required to have a valid UK driver’s license and at least one year’s driving experience. Furthermore, due to the potential risk of motion sickness in the driving simulator, the drivers were required to take part in a simulator sickness check to determine their susceptibility to the symptoms of motion sickness. Drivers who were found to be susceptible to motion sickness were not allowed to take part in the study. The drivers who took part were paid £10 in cash for their involvement.

5.5 THE TASKS

The drivers were assigned a navigation task with the virtual car head-up display whilst driving. The aim of the navigation task was to determine whether the drivers would correctly follow the turns on the route to reach the destination with the virtual car head-up display.

5.6 THE PROCEDURES

At the start of the study, the drivers were divided into two groups of three and two. There were two routes designed for the study. The first was a motorway whilst the second was an urban environment. The drivers each drove on the two routes in a counter-balanced format i.e. the group which had the three drivers drove on the urban route first and then the motorway whilst the group which had the two drivers drove in the reverse order. Both routes had vehicle traffic of medium density. During the drives, there were video recordings of the drivers which were used to identify how the drivers followed the virtual car along the routes. This approach was adopted because the virtual car head-up display prototype was not tied to the simulator software.

The Wizard-of-Oz approach was used to control the behavior of the virtual car in the driver’s field of view during the drives. The experimenter sat in a separate location in the simulator room whilst the participants sat in front of the driving simulator. After performing the assigned tasks in the simulator, the drivers were invited to an interview session where they were asked questions about the design concept e.g. how the navigation context affected interaction with the virtual car, how easy the navigation instructions from the virtual car were to follow and whether the virtual car distracted them from focusing on the road scene. The interview sessions were recorded using an audio recorder.

5.7 THE DATA ANALYSIS

The video data were analyzed during playback by observing how each of the drivers reacted to the virtual car when it provided navigation instructions needed to stay on the route. The number of navigation errors made by the drivers were checked to assess whether the drivers stayed on the route whilst following the virtual car. The audio data from the interview sessions were transcribed and the responses which the drivers provided based on the questions they were asked about the virtual car head-up display were noted. The transcripts are attached in Appendix D section of this thesis.

5.8 THE KEY FINDINGS

There were several key findings which were identified from the study which are outlined as follows:

- The virtual car head-up display was more useful in the urban environment than on the motorway: Based on how the navigation context affected interaction with the virtual car head-up display, the drivers indicated that the virtual car head-up display was more useful in the urban environment than on the motorway. This was because there was more work to be done in the urban environment as the virtual car head-up display indicated and turned at junctions. There was less work done in the motorway which was a long stretch of road and where only lane changes were made. One driver when asked how useful he found the virtual car head-up display in the different navigation contexts provided the following response:

  - Driver X: For example, I guess like on the motorway example, it was probably less useful just because it was a long stretch and you are not likely to be doing anything other than changing lanes. But in the urban environment example, it is more useful because there are corners to turn around and junctions with traffic lights and things like that.

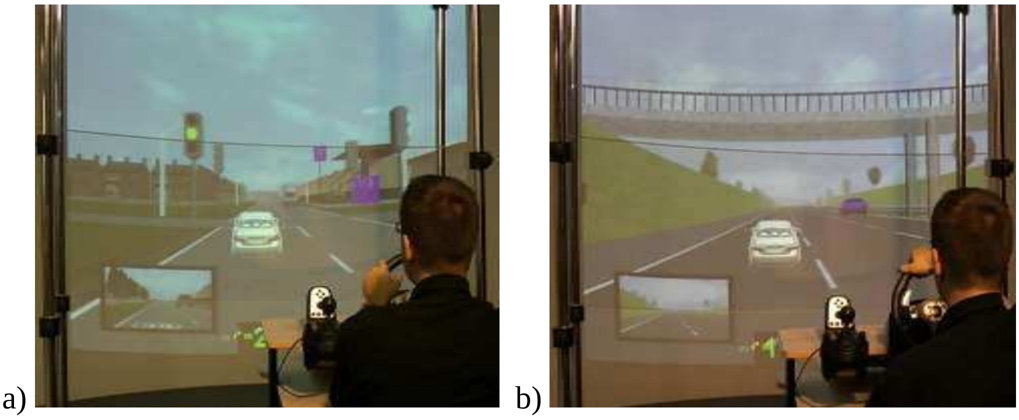


Figure 5.2: a) Urban environment with turns b) Motorway without turns

- The drivers modified their behaviour on approaching traffic lights: It was observed that all of the drivers left gaps between their vehicle and the white line at red traffic lights in the urban environment. The virtual car was seen to fit within the gaps when the drivers stopped at red traffic lights. Instances of these from the video recordings are shown in Figure 5.3.

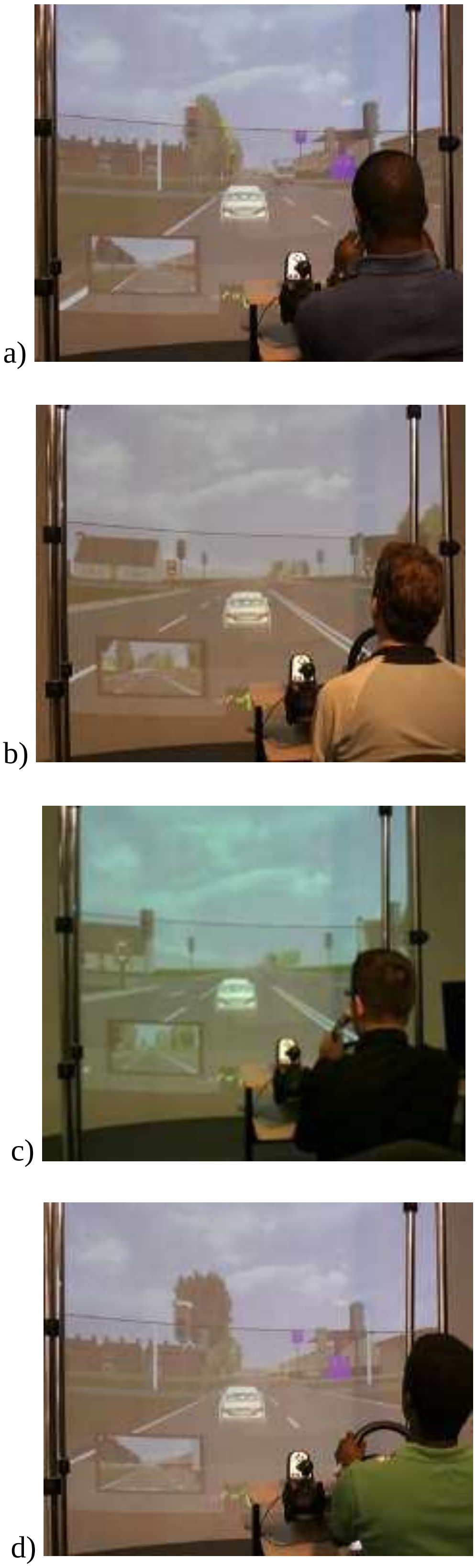


Figure 5.3: Drivers leaving gap in front of white line

- The drivers valued the novel concept of the virtual car head-up display: The drivers said during the interview sessions that the virtual car head-up display was a good way to present navigation instructions. A driver who uses a vehicle navigation system in the real world commented that when compared with his vehicle satellite navigation system, the virtual car head-up display allowed more visual attention to be allocated to the forward road scene. When asked how easy the navigation instructions from the virtual car were to follow and how using it compared with using a vehicle satellite navigation system, the driver provided the following response:
    - Driver D: To the best of my knowledge, with my experience of using a vehicle satellite navigation system and this virtual car head-up display, this obviously makes me to be more focused on the road and does not really distract me which is quite interesting. Also based on the idea that the car can indicate when to turn or when not to turn that was good. It uses the real view of the environment which the vehicle satellite navigation system does not do.

  Another driver was also asked how he perceived the virtual car head-up display would fit with real world driving. He provided the following response:

    - Driver S: Drivers can relate to the behaviour of the virtual car because they follow other vehicles while driving on the road and

> see these actions displayed by other vehicles. That is, the virtual car kind of tells you which way to follow the car.

- The virtual car head-up display design concept was feasible and usable: The behaviors of the drivers when following the virtual car head-up display in the study were compared with the sequence of actions in the car following field study conducted in this research. The comparison showed that the drivers followed the navigation instructions from the virtual car head-up display in the same way that the trailing driver followed the lead driver along the route. Illustrations of this are shown in Figures 5.4, 5.5 and 5.6.

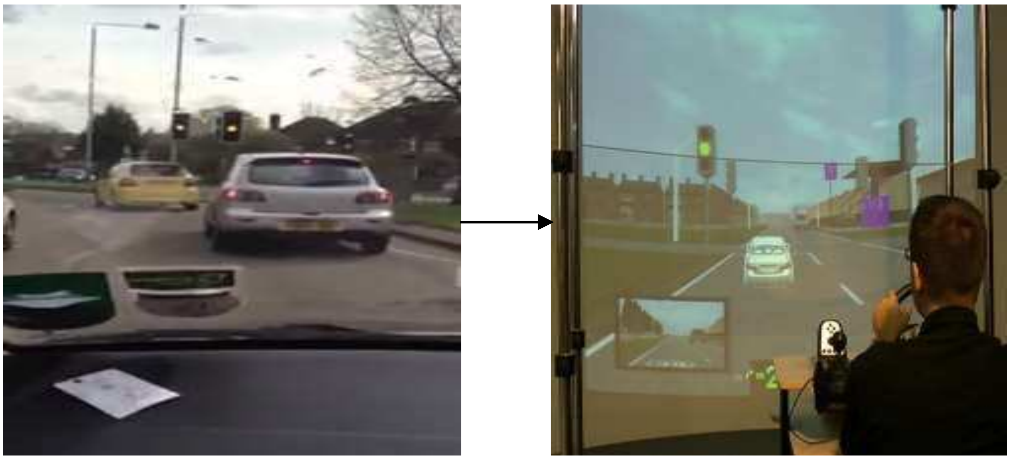


Figure 5.4: Stopping at traffic lights

Figure 5.5: Lane positioning

Figure 5.6: Providing turn instructions

5.9 DISCUSSION

Based on the evidence from the study, it can be seen that the drivers were able to follow the navigation instructions from the virtual car in leading them to the destination. The comparison which was made between the field study conducted as part of this research and this study was able to highlight similarities in the “car-following” approach for leading drivers along a route. The actions of the virtual car e.g. regarding lane positioning, turning and indicating which were successfully executed by the drivers when they were provided showed that the design concept is an intelligible way of presenting navigation instructions. The drivers seemed to have a good understanding of the navigation instructions from the virtual car head-up display and this made it easy for them to provide the correct responses. It was based on this observation that the virtual car head-up display concept was deemed feasible and the virtual car to be usable as a navigation tool. The drivers encouraged the further development of the virtual car head-up display because they felt that it would be a useful navigation tool which drivers can have at their disposal to provide navigation assistance.

The area of concern with the virtual car head-up display was the unusual gaps which were left at traffic lights in the urban environment route. It may have been that the drivers perceived the virtual car to be another car out on the road and as a result may have driven to accommodate the virtual car within the gaps. It may be possible that this may have been caused as a result of the appearance of the virtual car which was collimated in the road scene where the drivers would have perceived the virtual car to exist in the real world instead of on the windshield. The situation may have been worsened by the fact that the virtual car was projected over a virtual environment which may have made it difficult for the drivers to easily distinct between the two displays. The simulator limitation where there was only a 60° view of the forward road may have also contributed to this problem because parts of the visual scene which would disappear if the driver moves close to the red traffic light may have caused them to try and fit the objects within the view while driving.

It would be useful to examine different formats of the virtual car head-up display based on collimation in order to determine whether these issues would reoccur. A conformity study can be useful to provide an indication as to whether this may reoccur because a non-conformal format would not place the virtual car as part of the external road scene. This can be planned as the next step in the usability evaluation of the virtual car head-up display. Also, a real world driving context where the simulator limitations are absent should clarify whether this would be a genuine concern in the design of the virtual car head-up display.

5.10 SUMMARY AND FUTURE WORK

The outcomes of this study have suggested that the concept of the virtual car head-up display is feasible and the virtual car head-up display is usable as a navigation tool. The drivers were able to execute the navigation instructions issued to them by the virtual car head-up display to reach their destination. The drivers encouraged the further development of the virtual car head-up display because they felt it has potentials to be a useful navigation tool which instructs drivers using techniques which align with the primary task of driving. This study highlighted an issue of concern surrounding the allocation of gaps in front of the red traffic lights by drivers. It would be useful to look into this in future work in order to understand possible reasons for such occurrences. Having identified that the concept of the virtual car head-up display is feasible, the next step in the development process would be to examine the conformity of the virtual car to determine what effect changing the conformity of the virtual car would have on driving behavior and performance. Such study may help to provide an indication of whether the gap allocation issue would reoccur as well as which conformity would be better suited for the virtual car in the head-up display.

CHAPTER

6

A STUDY WITH THE VIRTUAL CAR HEAD-UP DISPLAY IN TWO CONFORMITY SYMBOLOGIES

6.1 INTRODUCTION

The findings from the previous study showed that the concept of following the virtual car on the windshield was feasible. That was the first of two usability evaluations which were part of the design process. The second usability evaluation which would determine the final design for the virtual car head-up display prototype would be a conformity study. It has been found in the literature from studies which studied the impacts of conformity symbologies in head-up displays that this factor can affect behavior and performance. For example, Gish and Staplin (1995) highlighted that head-up displays in aviation have often employed conformal symbology where the displayed information is perceived as part of the external scene. They found that conformal symbology head-up displays were associated with better performance when compared with non-conformal symbology head-up displays which were associated with degraded performance. Also, Foyle et al. (2005) found that “scene augmentations” which represent adding virtual, non-real, three-dimensional objects drawn on the HUD as if they existed at a location in the real world produced better situational awareness, subjective ratings and improved the detection of off-nominal situation awareness probe events which occurred in the environment when compared with those which did not appear to exist in the real world.

This chapter focuses on highlighting findings from the conformity study which is conducted with two conformity symbologies (conformal and non-conformal) for the virtual car head-up display. Conformity in this study is referenced to the external environment. In the conformal symbology, the virtual car is conformed to the external road scene so that its actions are referenced within that environment. In the non-conformal symbology, the virtual car is not conformed to the road scene of the external environment. Instead, it is conformed to a road underneath the virtual car so that its actions are referenced to that road. The road which is shown underneath the virtual car represents a section of the road in the simulated environment which is driven in. It is expected that the findings from this study would indicate which of the two conformity symbologies is better suited for the virtual car so that this can be used in the eventual design.

6.2 THE AIM OF THE STUDY

The study was conducted to determine how conformity changes for the virtual car head-up display would affect the drivers' behaviour and performance in the primary task of driving. The findings would indicate which conformity produces better results with the virtual car and as a result could be used for the final design of the virtual car head-up display.

6.3 THE SETUP

The conformity study was conducted in a controlled laboratory setting which comprised of hardware and software components.

The hardware components

There was an interconnected game steering wheel controller and pedals system which were used to control the movement of the vehicle in the simulated road. There was a piece of glass perspex which was used as the windshield upon which the virtual car head-up display symbologies were projected. The virtual car conformity symbologies were projected on the windshield from a 23" monitor which was placed at a 45° angle below the dashboard. A projector was used to display the simulated environment in front of the drivers. A video recorder was used to capture data on the actions of the drivers during the study.

The software components

There was the STISIM (Systems Technology Incorporated Simulator) software which was used to design the virtual environment. There was also the Microsoft PowerPoint software which was used to design the mockups for the conformities of the virtual car head-up display. The conformal and non-conformal head-up display symbologies examined in the study are described as follows:

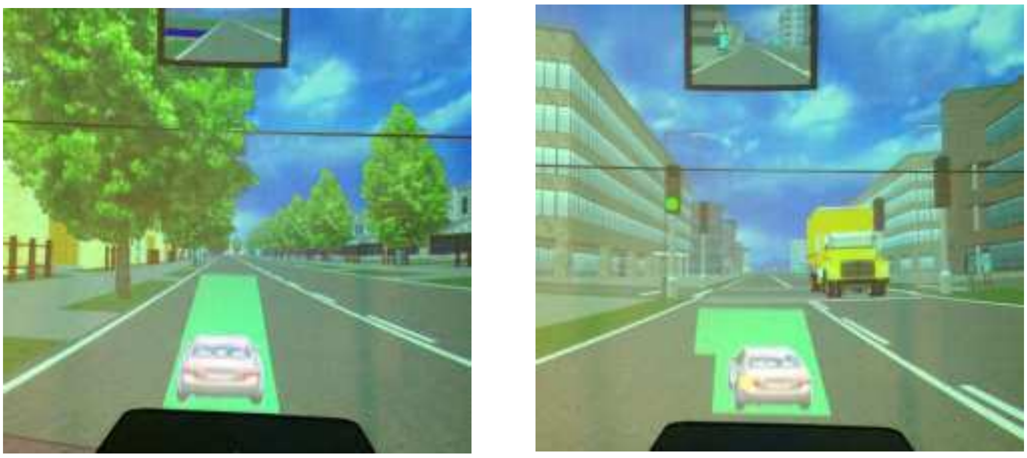
Conformal head-up display symbology

In the conformal head-up display symbology, the virtual car was superimposed on the external environment by itself. The actions of the virtual car were tailored to fit with the external environment. This was the format used in the previous study and is shown in Figure 6.1.

Figure 6.1: Conformal head-up display symbology

Non-conformal head-up display symbology

In the non-conformal head-up display symbology, the virtual car was not conformed to the road scene of the external environment. Instead, it was conformed to a road underneath the image which was a representation of the external environment driven in. The actions of the virtual car were tailored to fit with the underlying road. Several examples of these are shown in Figure 6.2.



Straight road Left turn ahead

Figure 6.2: Non-conformal head-up display symbology

6.4 THE PARTICIPANTS

Twenty drivers took part in the study (fifteen males and five females) who were resident in Nottingham. The drivers were aged between 18 and 38 years (average age was 34.2 years) and were selected to take part based on eligibility in certain criteria. They were required to have a valid UK driver's license and at least one year's driving experience. Furthermore, due to the potential risk of motion sickness in the driving simulator, the drivers were required to take part in a simulator sickness check to determine their susceptibility to the symptoms of motion sickness. Drivers who were found to be susceptible to motion sickness were not allowed to take part in the study. The drivers who took part were each given a £10 Amazon voucher for their participation in the study.

6.5 THE TASKS

The drivers were required to control the movement of the vehicle in the simulated environment using the simulator controls. This was the primary task of driving. They were also required to find their way along a route by following the virtual car head-up display navigation instructions. This was the navigation task. In the primary driving task, variables which could be used to infer distraction with the virtual car in both conformity symbologies were measured e.g. speed, lane deviation and gap allocation to vehicles ahead in the lane. Young et al. (2003) suggested that these variables are useful for determining the distraction potentials with In-Vehicle Systems. The PDE (Pre-Determined Event) files in the driving simulator software were used to capture data for these variables.

- Speed: Very slow speeds were used to determine possible compensatory effects due to difficulty in using a head-up display symbology.
- Lane deviation: The standard deviations in the lane were used to determine patterns of weaving in the lane position which occurred as a result of lack of attention to the steering angle.
- Gap allocation: The gap allocation to vehicles ahead in the lane driving at constant speed were used to determine whether drivers increased their gap allocation with each conformity symbology.

In the navigation task, variables which could be used to determine how drivers used each of the conformity symbologies to find their way along the route were measured. In this task, navigation performance, success rates and times taken to execute the navigation instructions (e.g. reacting to indicating instruction) were measured. The video recordings were used to capture data for these variables because the virtual car head-up display was not tied to the simulator software.

- Navigation performance: This was measured to determine which of the conformity symbologies supported better navigation performance for the drivers. This variable was determined by identifying the percentage of the correct turns on the route which were followed by the drivers.

- Success rates in executing the indicating instruction: This was measured to determine the percentage value of the indicating instruction which was successfully replicated by the drivers with each of the conformity symbologies. This variable was measured by identifying the number of times the indicating instruction was issued against the number of times the drivers replicated the instruction. The values obtained would be used to identify how willing the drivers were in displaying safe driving actions with each of the conformity symbologies of the virtual car head-up display.
- Reaction times: The reaction times were used to determine the time taken by the drivers to execute the navigation instructions after they were provided by the virtual car. The values obtained would be used to identify the ease with which the drivers understood the navigation instructions which were provided by the virtual car head-up display.

6.6 THE PROCEDURES

The drivers were divided into two groups of ten and a counter-balanced format for each group of drivers with the conformity symbologies was adopted as shown in Table 6.1.

Table 6.1: Format for groups and conformity symbologies in the drives

Group no.	1st drive symbology	2nd drive symbology
1	Conformal symbology	Non-conformal symbology
2	Non-conformal symbology	Conformal symbology

The drivers each took a test drive before the start of the study to familiarize with the controls and settings before commencing the main drive. In the test drive, a short route with no traffic which comprised of only one left and right turn was used. The virtual car head-up display symbologies were not used at this stage and as a result no data was collected. On completing the test drive, the drivers commenced the main drive where a within-subject design approach (see Erlebacher, A., 1977; Greenwald, A. G., 1976; Venkatesh, V. and Johnson, P., 2002) was adopted to counter-balance the study conditions. At this stage, the virtual car head-up display symbologies were displayed on the windshield and data was measured.

The Wizard-of-Oz approach was adopted in the study when controlling the behavior of the virtual car during the drives. After each drive with a conformity symbology was completed, the drivers filled out a questionnaire so that there could be qualitative data gathered about their experience. The questionnaire had two sections; a NASA-TLX and preference section. Irune (2009) indicated that the NASA-TLX is a standardized questionnaire which is used to subjectively measure cognitive workload and mental effort required to perform a task. The NASA-TLX (see Appendix section A) was used to obtain ratings for the virtual car in both of the conformity symbologies on six different subscales; physical, mental and temporal demand, effort, frustration and performance.

The physical demand was the demand on the drivers e.g. through the use of eyes, hands, legs etc. The mental demand was the amount of cognitive processing work which the drivers felt that they put in to perform the tasks. The temporal demand was the demand associated with the pace of the task performed such that faster tasks would imply a higher temporal demand. The effort was the level of commitment of the drivers to perform their assigned tasks. The frustration was the level of irritation, stress or discouragement the drivers felt when performing the task. The performance was the level at which the drivers carried out the task. Each of these subscales had five levels (1-5). Demand levels were 1 – low, 2 – mid low, 3 – medium, 4 – mid high and 5 – high. Effort levels were 1 – little, 2 – not so much, 3 – intermediate, 4 – much and 5 – a lot. Frustration levels were 1 – no frustration, 2 – a little frustration, 3 – average frustration, 4 – frustrating and 5 – very frustrating. Performance level were 1 – poor, 2 – not so good, 3 – fair, 4 – good and 5 – excellent. Finally, the drivers were asked which of the two conformity head-up display symbologies they preferred in the preference section of the questionnaire.

6.7 THE DESIGN OF THE SCENARIOS

There were two types of scenarios used in the study; the conformity symbology scenarios and simulated environment scenarios. The conformity symbology scenarios have been described earlier in this chapter. Each of the routes in the simulated environment were designed to have the same complexity levels e.g. road conditions, pedestrian activity and medium vehicle traffic density where the vehicles were travelling at a constant speed of 40mph. They would slow down and stop on approaching a red traffic light. The routes had five correct turns in total (apart from other turns on the roads) which would be followed to reach the destination. There were differences in the routes design e.g. one route required the drivers to take two left turns and three right turns while the other route required the drivers to take three left turns and two right turns. Also, the sequence of the turn directions was varied to reduce the drivers' anticipation of the direction of turn.

The driver's ability to follow these correct turns would be examined to determine whether there would be any impact on navigation performance due to the change in conformity. For each correct turn missed, the driver's navigation success rate would be negatively affected. Furthermore, the conformity symbologies were counter-balanced amongst the drivers for each of the scenarios of the simulated environment. It is anticipated that the average time it would take for each drive in the study is about 10 minutes.

6.8 THE DATA ANALYSIS METHODS

The data collected by the simulator software on speed, lane deviation and gap allocation, the numerical data from the video recordings on success rates in the tasks performed and ratings in the NASA-TLX questionnaire would be statistically analyzed using a paired two-tailed t-test distribution method to check for differences between the means of the variables. If a difference is observed between the means of a measured variable, then it would be suggested that a change in the conformity symbology had an effect on the outcome. However, if no difference is observed between the means of a measured variable, then it would be suggested that a change in the conformity symbology did not have any effect on the outcome.

6.9 THE HYPOTHESES

Null and alternative hypotheses were outlined in the study. The null hypothesis (H_0) is a statement which suggests that there would be no difference between the conditions when the independent variable is changed. The alternative hypothesis (H_1) is a mutually exclusive statement to the null hypothesis. A significance value of $p < 0.05$ is used in this study. The main goal of this study is to find statistical evidence which refutes the null hypotheses so that the alternative hypotheses is supported. There are several null and alternative hypotheses which would be examined after a change in the conformity symbology of the head-up display is made. The hypotheses are outlined as follows:

Hypothesis 1: Impact on speed

H_0: No significant difference; H_1: Significant difference.

Hypothesis 2: Impact on standard deviation in lateral lane position

H_0: No significant difference; H_1: Significant difference.

Hypothesis 3: Impact on gap allocation to vehicles ahead in the lane

H_0: No significant difference; H_1: Significant difference.

Hypothesis 4: Impact on navigation performance

H_0: No significant difference; H_1: Significant difference.

Hypothesis 5: Impact on success rates in executing the navigation instructions

H_0: No significant difference; H_1: Significant difference

Hypothesis 6: Impact on reaction times to executing the navigation instructions

H_0: No significant difference; H_1: Significant difference.

6.10 RESULTS

The paired two-tailed t-test which was carried out on the data highlighted the following results:

6.10.1 MEAN SPEEDS

A significant difference in the mean speeds was obtained after a change in the conformity symbology was made: paired [t (19) = 6.33, p = .000]. With the conformal symbology, the mean speed value was 30.83 mph whilst for the non-conformal symbology the value was 31.87 mph. This resulted in a difference in the mean speeds of 1.04 mph. It was concluded that a change in the conformity symbology had a significant effect on the speed of the drivers. This led to the null hypothesis being rejected. The mean values with standard deviation bars for speed of the drivers in both conformity symbologies are shown in Figure 6.3.

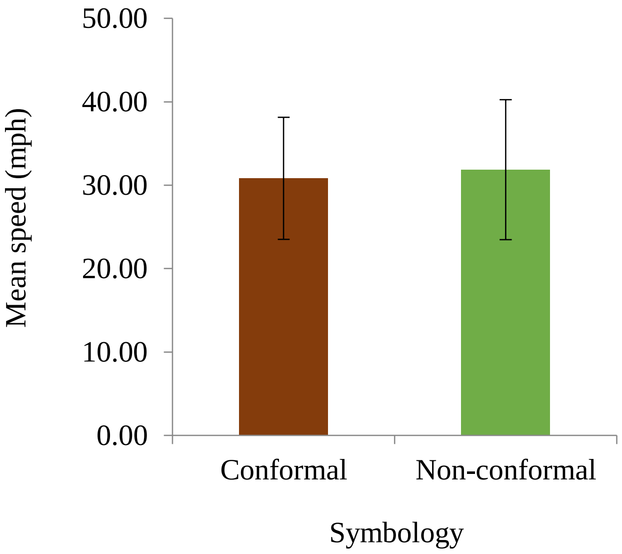


Figure 6.3: Mean speed

6.10.2 MEAN STANDARD DEVIATIONS OF LATERAL LANE POSITION

A significant difference in the mean standard deviations of lateral lane position was obtained after a change in the conformity symbology was made: paired [t (19) = 2.027, p = 0.057]. With the conformal symbology, the mean standard deviation in lane position was 1.11 feet whilst for the non-conformal symbology, the mean standard deviation in lane position was 1.31 feet. This resulted in a difference in the mean lateral lane position of 0.2 feet. It was concluded that a change in the conformity symbology resulted in a significant effect on the drivers' lateral deviation in the lane. This led to the null hypothesis being rejected. The mean values with standard deviation bars for the lateral lane position of the drivers in both conformity symbologies are shown in Figure 6.4.

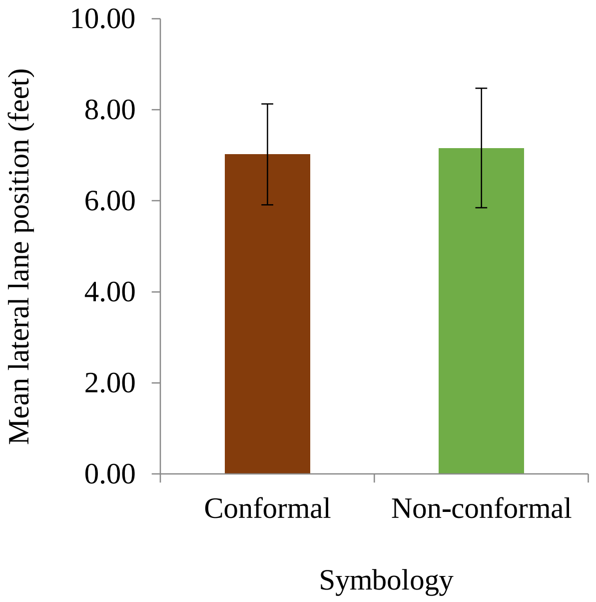


Figure 6.4: Mean lateral lane position

6.10.3 MEAN GAP ALLOCATION TO VEHICLES AHEAD IN THE LANE

No significant difference in the gap allocation to vehicles ahead in the lane was obtained after a change in the conformity symbology was made: paired [t (19) = 1.003, p = 0.328]. With the conformal symbology, the mean gap allocation was 378.81 feet whilst for the non-conformal symbology the mean gap allocation was 372.85 feet. This resulted in a difference in the mean gap allocation of 6.04 feet. It was concluded that the difference obtained for the mean gap allocation to vehicles ahead in the lane in both conformity symbologies was likely due to chance rather than the manipulation of the conformity symbologies. This led to the alternative hypothesis being rejected.

6.10.4 NAVIGATION PERFORMANCE

All twenty drivers took the five correct turns on both routes with the conformity symbologies. This meant that the drivers achieved a 100% navigation success rate with both conformity symbologies. This led to the alternative hypothesis being rejected.

6.10.5 MEAN SUCCESS RATES FOR EXECUTING NAVIGATION INSTRUCTIONS

No significant difference in the mean success rates for executing the navigation instructions was obtained after a change in the conformity symbology was made: paired [t (19) = 0, p = 1.000]. The mean success rate for executing the navigation instructions was 90% for both the conformal and non-conformal symbologies which meant that there was no difference in the mean success rates obtained. This led to the alternative hypothesis being rejected.

6.10.6 MEAN REACTION TIMES TO EXECUTE THE INDICATING INSTRUCTION

A significant difference in the mean reaction times to execute the indicating instruction was obtained after a change in the conformity symbology was made: paired [t (19) = 2.97, p = 0.01]. With the conformal symbology, the mean reaction time was 2.6 seconds whilst for the non-conformal symbology, the mean reaction time was 3.02 seconds. This resulted in a difference in the mean reaction times of 0.42 seconds. It was concluded that a change in the conformity symbology resulted in a significant effect on the mean reaction times to execute the indicating instruction. This led to the null hypothesis being rejected. The mean values with standard deviation bars for the reaction times to execute the indicating instruction in both conformity symbologies are shown in Figure 6.5.

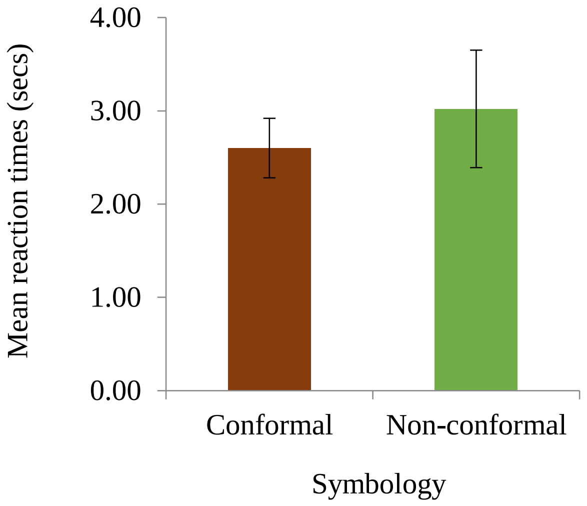


Figure 6.5: Mean reaction times to execute indicating instruction

6.10.7 SUBJECTIVE RATINGS IN QUESTIONNAIRE

The findings obtained from the ratings in the NASA-TLX are as follows:

Mean physical demand

No significant difference in the mean physical demand was obtained after a change in the conformity symbology was made: paired [t (19) = 1.831, p = 0.083]. For the conformal symbology, the mean physical demand was 1.35 whilst for the non-conformal symbology, the mean physical demand was 1.5. Therefore, the difference in the mean physical demand was 0.15.

Mean mental demand

No significant difference in the mean mental demand was obtained after a change in the conformity symbology was made: paired [t (19) = 1.453, p = 0.163]. For the conformal symbology, the mean mental demand was 2.35 whilst for the non-conformal symbology, the mean mental demand was 2.45. Therefore, the difference in the mean mental demand was 0.1.

Mean temporal demand

No significant difference in the mean temporal demand was obtained after a change in the conformity symbology was made: paired [t (19) = 1.000, p = 0.330]. For the conformal symbology, the mean temporal demand was 1.95 whilst for the non-conformal symbology, the mean temporal demand was 1.85. Therefore, the difference in the mean temporal demand was 0.1.

Mean effort

No significant difference in the mean effort was obtained after a change in the conformity symbology was made: paired [t (19) = 0, p = 1.000]. The mean effort for both the conformal and non-conformal symbologies was 2.35 which meant that there was no difference.

Mean frustration

No significant difference in the mean frustration was obtained after a change in the conformity symbology was made: paired [t (19) = 0, p = 1.000]. The mean frustration for both the conformal and non-conformal symbologies was 1.75 which meant that there was no difference.

Performance

No significant difference in the mean performance was obtained after a change in the conformity symbology was made: paired [t (19) = 1.831, p = 0.083]. For the conformal head-up display symbology, the mean performance was 3.8 whilst for the non-conformal symbology, the mean performance was 3.65. The difference in mean performance was 0.15.

The second part of the questionnaire was used to obtain ratings for the preference between the two conformity symbologies. The finding is provided as follows:

Preference

For the preference section, fourteen drivers preferred the conformal symbology whilst six drivers preferred the non-conformal symbology. These are shown in Figure 6.6.

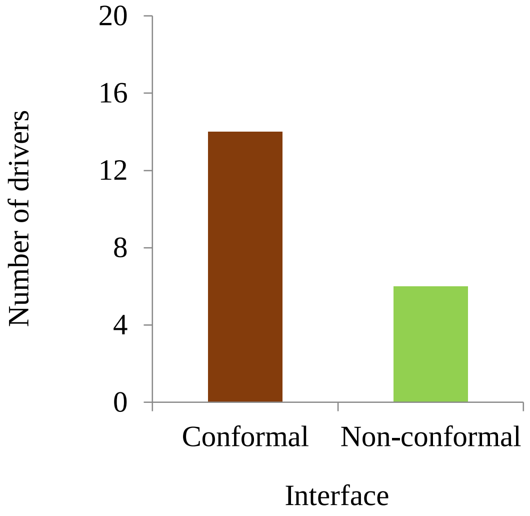


Figure 6.6: Preference of conformity symbologies

6.11 DISCUSSION

The findings suggested that a change in the conformity symbology of the virtual car in the head-up display had an effect on the behavior and performance in the driving task. The lower values which were obtained for the deviation in the lane and reaction times to execute the indicating instruction with the conformal symbology suggested that there was less cognitive workload demand on the drivers when compared with the non-conformal symbology. These were further confirmed in the NASA-TLX through the subjective ratings which suggested that the conformal symbology did not affect the drivers' workload as much as the non-conformal symbology.

Tailoring the virtual car in the external road scene in the conformal symbology was associated with less cognitive workload because it was suggested from the findings that the addition of the road underneath the virtual car in the non-conformal symbology may have caused an additional work of translation for the drivers. It was possible that the drivers would have had to match the road underneath the virtual car to the external road scene which would increase their cognitive workload. From the findings, it was assumed the differences in the mean lane position and deviation could be attributed to situations where the drivers were not just looking at the virtual car but also the road underneath it in the non-conformal symbology. The work which would have been involved in monitoring the road underneath along with the virtual car may have caused the drivers to not allocate adequate attention to their steering wheel angle when compared with the virtual car in the conformal symbology. It is possible that there would have been longer glances at the virtual car in the non-conformal symbology to keep track of when changes in the road underneath would occur.

Also, when examining the reaction times to execute the indicating instruction, it was assumed that the drivers reacted slower to indicate in the non-conformal symbology because of the change in not just the virtual car but also the road underneath. It is possible that there were longer glances at the information in the head-up display to fully understand the expected response. Possibly, allocating attention to the different information in the non-conformal symbology when an action was to be performed may have caused the drivers to react slower when executing the indicating instruction. This can be tied to increasing the amount of information or complexity in the head-up display and Burnett and Donkor (2012) showed that such increase can have an effect on the behavior and performance of drivers. Hence, it can be suggested that limiting the amount and complexity of information provided to drivers in a similar type of head-up display could help to reduce the work of translating the information in the head-up display to the external environment.

It was also useful that there was a good correlation established between the representation of the road underneath the virtual car in the head-up display and the external environment as it is possible that this can affect the ease with which the drivers understand what actions should be carried out and where they should be done. A poor correlation could cause usability issues for the drivers where there is confusion of what they should do. For example, if the information in the non-conformal symbology does not match with that in the external scene, the drivers may receive wrong turn instructions which would cause navigation errors and increase the time and effort to complete a journey. This was not a concern with the conformal symbology because the virtual car was collimated with the simulated road and the navigation instructions were tailored to fit within the external environment. This helped to eliminate the need to match information between different roads. It was therefore suggested that displaying the virtual car as part of the simulated environment in the conformal symbology was helpful for reducing the cognitive workload which was required during navigation.

The subjective ratings obtained in the NASA-TLX showed similar outcomes in the demands of the two conformity symbologies. However, there was more preference for the virtual car in the conformal symbology which may have been due to the lower complexity levels when compared with the non-conformal symbology. Overall, it was found that the conformal symbology resulted in better behavior and performance when compared with the non-conformal symbology. This suggestion is in line with the suggestion from Gish and Staplin (1995) based on how conformal and non-conformal symbologies affect behavior and performance. Also, it is in line with the suggestion from Foyle et al. (2005)

relating to how scene augmentations which appear as part of the real world result in better performance.

6.12 SUMMARY AND FUTURE WORK

The outcomes from this study showed that there were some differences in the quantitative and qualitative data measured. Overall, the drivers performed better with the virtual car in the conformal symbology when compared with the non-conformal symbology. Subjective ratings which were obtained from the drivers indicated that there were more who drivers preferred to use the virtual car in the conformal symbology than the non-conformal symbology. This was used as a basis for suggesting that the conformal symbology is a better way to present the navigation instructions to drivers in the head-up display. Hence, the conformal symbology for the virtual car is the eventual outcome of the design for the virtual car head-up display.

Having pointed out that the design process for the virtual car has been concluded and that the virtual car would be conformed to the external road scene when drivers are issued with navigation instructions, it is now important that a usability evaluation be conducted which compares the virtual car head-up display with its existing navigation system counterparts. The comparison would serve as a basis for identifying which of the navigation systems support drivers in optimally performing the primary task of driving. This would be the focus of the next chapter.

CHAPTER

7

AN EXPERIMENT COMPARING THE VIRTUAL CAR HEAD-UP DISPLAY WITH PROTOTYPES OF EXISTING NAVIGATION SYSTEMS

7.1 INTRODUCTION

In the previous experiment, the conformity of the virtual car head-up display was examined and the conformal symbology was suggested to be the better way to present the navigation instructions in the head-up display. An important usability evaluation would be to examine the impacts which driving with the virtual car head-up display would have on drivers when it is compared against its existing navigation system counterparts. This has therefore been earmarked as the next step in the evaluation process of the virtual car head-up display. Therefore, the focus of this chapter is to discuss an experiment which examined how drivers followed the navigation instructions provided by the virtual car head-up display (conformal head-up display) when compared with the prototypes of an arrow head-up display (non-conformal head-up display) and vehicle satellite navigation system (non-conformal head-down display). There was measurement of a number of navigation performance-related data in the experiment. Furthermore, there was measurement of several workload and distraction-related data in the driving simulator to identify how the virtual car head-up display compared with the other navigation systems in terms of the workload demands and level of distraction imposed on the drivers. The outcomes from the experiment are discussed in light of current literature.

7.2 THE AIMS OF THE EXPERIMENT

The experiment was conducted to compare how the use of the three navigation systems affected the workload demands and risk of distraction for the drivers when performing their assigned tasks. Furthermore, the navigation performance of the drivers with each of the navigation systems was examined to identify their usability in the navigation task.

7.3 THE EXPERIMENT SETUP

The experiment was conducted in a controlled laboratory setting using several software and hardware components.

Software components

These comprised of the STISIM (Systems Technology Incorporated Simulator) software which was used in the design of the simulated environment as well as Microsoft PowerPoint which was used in the design of the mockups for the three navigation systems.

Hardware components

These comprised of an interconnected game steering wheel controller and pedals system which were used to control the movement of the vehicle in the simulated environment. There were two video recorders placed around the drivers in the simulator room to capture data on their driving behavior and performance. The first video recorder was placed at a 45° angle and a distance of approximately one meter in front of the drivers. This video recorder was used to capture the eye glances and head movements which the drivers made from the road scene and towards the navigation systems. The second video recorder was placed at the rear of the room to capture data for the extra tasks which the drivers performed during the experiment. The virtual car and arrow head-up displays were projected on the perspex glass from a 23” monitor which was placed at 45° below the windshield and at a distance of three meters from the drivers (see Figure 7.1a and b). The vehicle satellite navigation system was displayed in a device located one metre in front of the drivers on the dashboard (see Figure 7.1c).

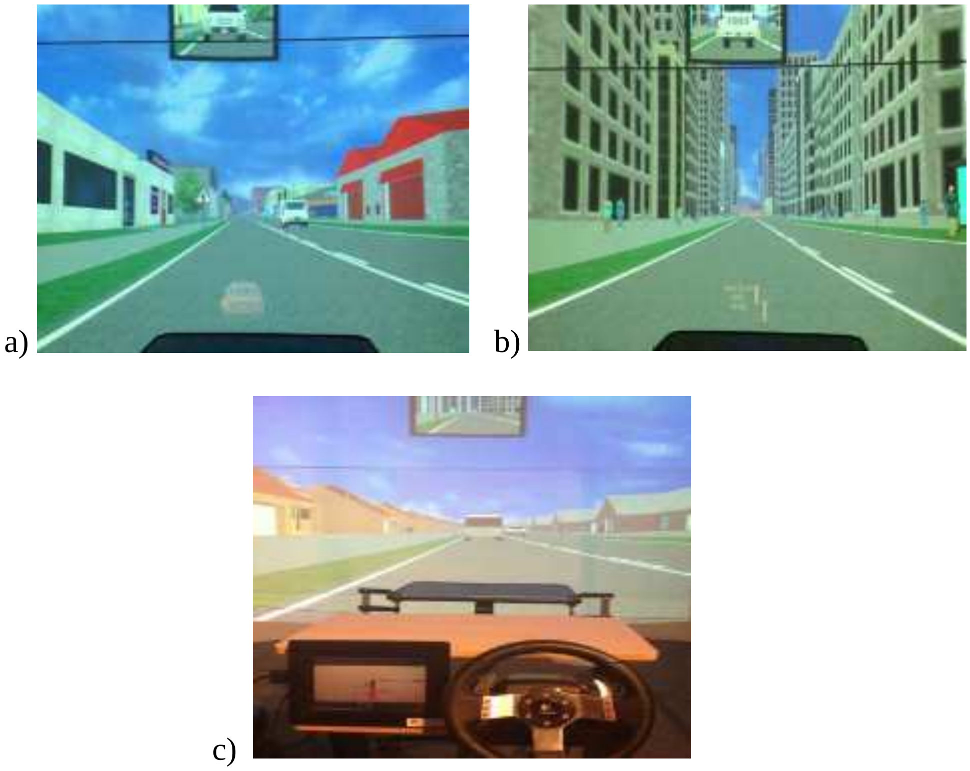
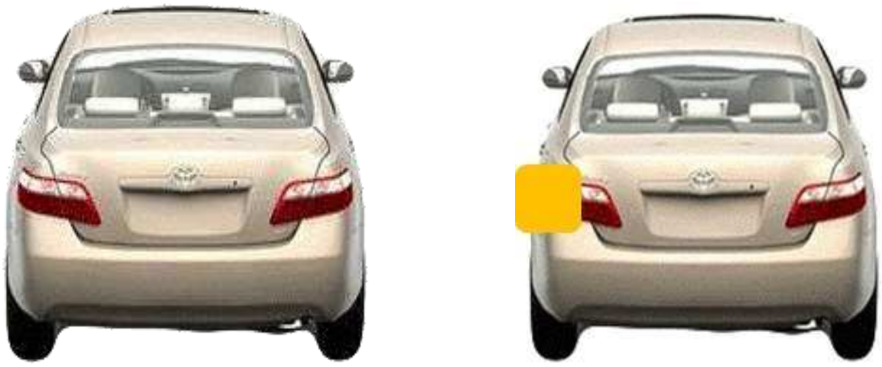


Figure 7.1: The navigation systems a) Virtual car HUD b) Arrow HUD c) Dashboard VSNS

The three navigation systems each presented different information to the drivers during the journeys. They are each described as follows:

The virtual car head-up display

The virtual car head-up display made use of visual and sound mechanisms (e.g. following the vehicle, staying in lanes, indicating and turning) to instruct the drivers along the routes. Several examples of the instructions provided are shown in Figure 7.2.



Virtual car going straight Virtual car indicating left

Virtual car indicating and turning left Virtual car indicating and turning right

Figure 7.2: Navigation information from virtual car head-up display

The arrow head-up display

The arrow head-up display presented drivers with only visual information on the windshield. There was written information which showed the street name and distance to the next turn. There was a distance bar which had a yellow fill and this emptied as the driver approached the junction where the turn would be made. Also, there was an arrow symbol which was used to indicate the direction of the next turn. Several examples of the instructions provided are shown in Figure 7.3.

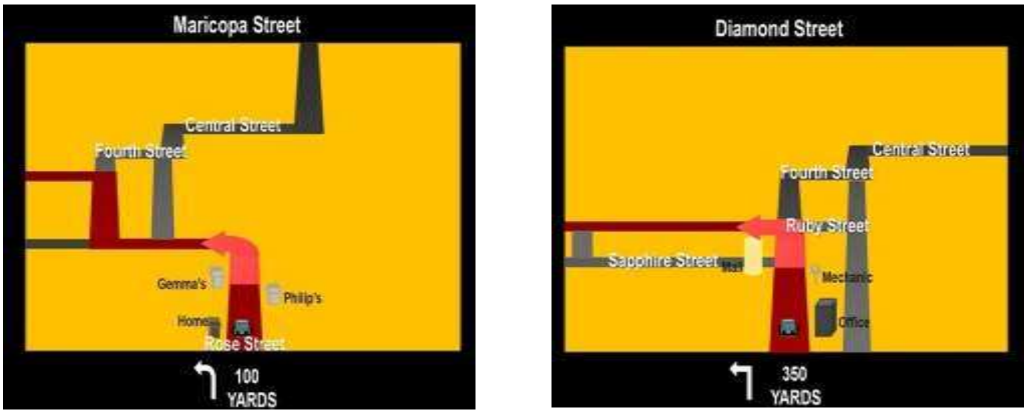
1000 yards from left turn 1500 yards from right turn

2000 yards from left turn 500 yards away from destination

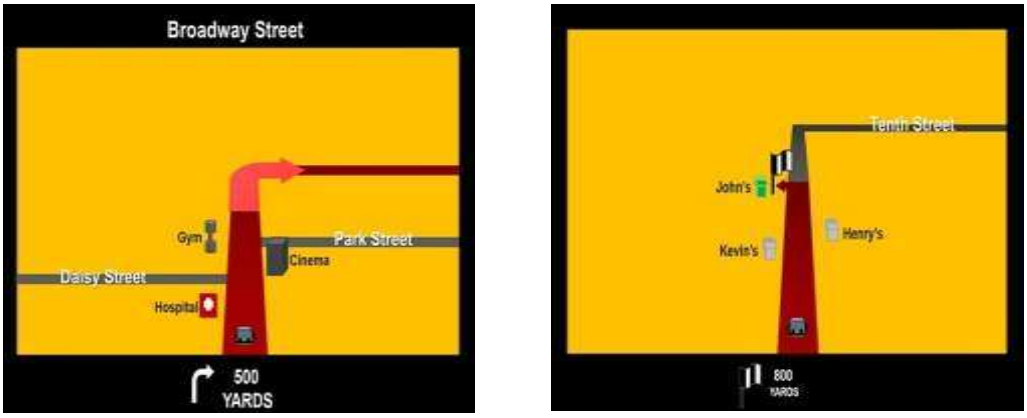
Figure 7.3: Navigation information from arrow head-up display

The vehicle satellite navigation system

The vehicle satellite navigation system made use of a visual map on the dashboard and spoken audio commands to instruct the drivers along the routes. Spoken commands such as “after 100 yards turn left”, “after 200 yards turn right” and “after 100 yards you have reached your destination” were amongst those issued to the drivers. The visual map displayed the route layout which was followed and provided information such as the distance to the next turn, turn direction, points of interest and street name of next turn. The position of the driver’s vehicle was indicated using a small car on the route. Several instances of the visual map layout are shown in Figure 7.4.



100 yards away from Maricopa street 350 yards away from Diamond street



500 yards away from Broadway street 800 yards away from destination

Figure 7.4: Navigation information from vehicle satellite navigation system

7.4 THE PARTICIPANTS

Thirty drivers took part in the experiment (twenty males and ten females) who were residents in Nottingham. The drivers were aged between 19 and 34 years (average age was 27.8 years) and were selected to take part based on eligibility in certain criteria. They were required to have a valid UK driver’s license and at least one year’s driving experience. Furthermore, due to the potential risk of motion sickness in the driving simulator, the drivers were required to take part in a simulator sickness check to determine their susceptibility to the symptoms of motion sickness. Drivers who were found to be susceptible to motion sickness were not allowed to take part in the study. The drivers who took part were each given a £10 Amazon voucher for their participation in the experiment.

7.5 THE TASKS

In addition to the primary task of driving, the drivers were assigned two extra tasks to perform. These were the navigation and peripheral detection tasks. In the primary driving task, the drivers were required to control the movement of the vehicle on the road of the simulated environment. Variables which could be used to infer distraction with the navigation systems were measured e.g. speed, lane position and gap allocation to vehicles ahead in the lane. Young et al. (2003) suggested that these variables are useful for determining distraction potentials with In-Vehicle Systems. Furthermore, indicating is perceived to be an important primary driving task which is performed to notify the surrounding drivers of a driver's intentions on the road. As a result, the success rates in indicating were measured and used to determine the level of attention which was assigned to replicating necessary safe actions with each of the navigation systems. There were five turns along the routes where the drivers were to indicate and the use of the indicator was checked at each turn to determine the success rates in this task. The PDE (Pre-Determined Event) files in the driving simulator software were used to collect data concerning the first three variables whilst the video recordings were used to collect data for the fourth variable.

- Speed: The speed values were used to determine any compensatory effect which the drivers display when there is difficulty in using a particular navigation system. Slower speeds can often indicate an increased level of difficulty in performing certain tasks and thus may suggest possible distraction.

- Lateral lane position: The standard deviations in the lateral lane position were used to determine the weaving effect which occurred as a result of lack of attention to the steering angle when using each navigation system.
- Gap allocation: The gap allocation to vehicles ahead in the lane driving at a constant speed were used to determine whether use of the navigation systems had an impact on the drivers’ gap allocation.
- Success rates in indicating: The number of times which the drivers indicated when making the turns were measured against the number of times when turns were to be made at the junctions on the route. This was used to determine the level of attention which the drivers allocated to performing the safe practices in the driving tasks.

The navigation task involved taking the correct turns on the route to a destination by following the instructions from a navigation system. The navigation systems used different mechanisms to present the drivers with navigation instructions e.g. virtual car head-up display used visual and sound mechanisms (car image and indicating sound), arrow head-up display used visual mechanisms only (arrow indicating direction of next turn, written information – current street name and distance to next turn and a distance bar) and the vehicle satellite navigation system used audio and visual mechanisms (spoken commands and visual route maps which included written information regarding distance to next turn and direction of next turn). Performance in the task was examined to identify the navigation ability of drivers with each of the navigation systems. If the drivers missed any of the turns, this would negatively affect their navigation success rates. Also, the frequency and duration of glances which were made away from the road when using each navigation system was measured. These were used to determine the potential visual distraction effects associated with use of each navigation system. There were video recordings used to monitor performance in the navigation task and the glance behaviors because the driving simulator software was not tied to the simulation of the navigation systems.

- Navigation success rates: The ability of the drivers to follow the correct turns on each route were examined so as to determine how the navigation systems supported the drivers in performing the navigation task. The success rates in the navigation task were measured by identifying the number of correct turns followed by the drivers against the maximum number of correct turns which the drivers were to follow.
- Glance frequencies: The glance frequencies were used to indicate the number of glances which the drivers made away from the road when using each navigation system. Higher glance frequencies at a navigation system would indicate increased risk of attention capture which could be used to suggest distraction.
- Glance durations: The glance durations were used to indicate the length of time which each glance that was made away from the road actually lasted. Longer glance durations at a navigation system would indicate increased attention capture and distraction.

Finally, a peripheral detection task was used to highlight periods of increased workload which could result in distraction of attention away from the road and towards a navigation system on the dashboard or windshield. This task was introduced in the experiment because there was a new variable; the location of the navigation systems. In this task, a peripheral object (a green arrow) appeared on either side of the road (see Figure 7.5).

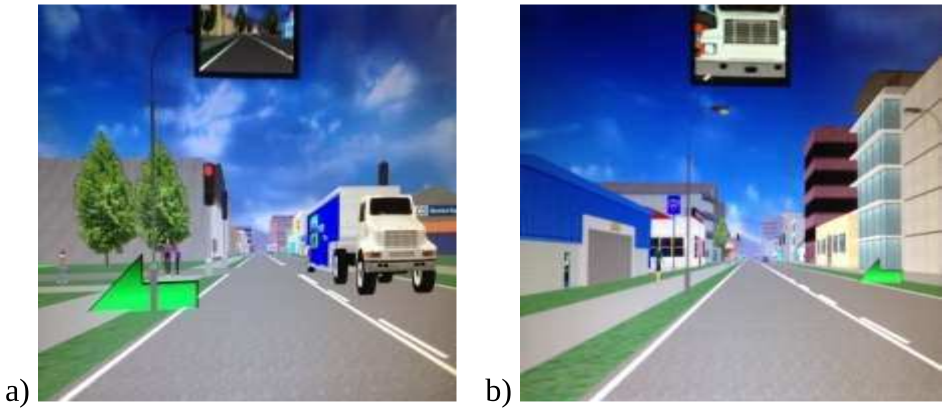


Figure 7.5: Peripheral object appeared a) On the left b) On the right

An input button mechanism on the steering wheel controller was pressed to indicate detection of the peripheral object. The arrow appeared five times in each drive and three of the five times which the arrow appeared coincided with times when navigation instructions were provided to the drivers. The ability of the drivers to detect the peripheral object whilst receiving the navigation instructions was examined. According to Mancero et al. (2007), the task is directly linked with hazard awareness and is considered a vital aspect of knowing the potential tunneling effect which is associated with an interface. The success rates for the detection of the object and reaction times to pressing the button were measured. Video recordings were used to monitor performance in this task.

- Success rates for detection of the peripheral object: These were used to determine how well the drivers detected the peripheral object. This was determined by comparing the number of times which the drivers pressed the input button against the number of times the peripheral object appeared.

- Reaction times to pressing the button: The reaction times to pressing the button were used to determine the length of time it would take the drivers to indicate that they had detected the peripheral object after it had appeared. This was determined by comparing the actual time difference between when the object appeared and when the drivers pressed the button.

7.6 THE PROCEDURES

The drivers were divided into three groups of ten. A counter-balanced format for the groups of drivers and navigation systems was adopted during the drives. This is shown in Table 7.1.

Table 7.1: Format for groups and interface use in the drives

Group no.	1st drive interface	2nd drive interface	3rd drive interface
1	Virtual car HUD	Arrow HUD	VSNS
2	Arrow HUD	VSNS	Virtual car HUD
3	VSNS	Virtual car HUD	Arrow HUD

The drivers were required to undertake a test drive at the start of the experiment to familiarize with the simulator setup. There was no data collected at this stage. Also, no navigation systems were used at this stage. After completion of the test drives, a within-subject design (see Erlebacher, A., 1977; Greenwald, A. G., 1976; Venkatesh, V. and Johnson, P., 2002) was then adopted to perform the main drives. The experiment conditions were counter-balanced to reduce the effect of the independent variable. The Wizard of Oz approach was adopted to control the behavior of the navigation interfaces during the main drives. A button on each slide was used to control the visual and audio instructions which were associated with each navigation interfaces. After each main drive, the drivers were provided with a NASA Task Load Index to rate the workload demands and performance with the navigation system used based on six subscales; physical, mental and temporal demand, effort, frustration and performance. Each of the subscales had five different levels (1-5).

The physical demand was the demand on the drivers e.g. through use of eyes, hands, legs etc. The mental demand was the amount of cognitive processing work which the drivers felt they put in to perform the task. The temporal demand was the demand associated with the pace of the task performed such that faster tasks would imply a higher temporal demand and vice versa. The effort was the commitment of the drivers to perform their assigned tasks. The frustration was the level of irritation, stress or discouragement the drivers felt when performing the task. The performance was the level to which the drivers performed the task. Each of these subscales had five levels (1-5). Demand levels were 1 – low, 2 – mid low, 3 – medium, 4 – mid high and 5 – high. Effort levels were 1 – little, 2 – not so much, 3 – intermediate, 4 – much and 5 – a lot. Frustration levels were 1 – no frustration, 2 – a little frustration, 3 – average frustration, 4 – frustrating and 5 – very frustrating. Performance level were 1 – poor, 2 – not so good, 3 – fair, 4 – good and 5 – excellent.

After the last main drive was completed, the drivers were provided with a further questionnaire which contained close-ended questions on three aspects; ease of use, level of distraction and preference for each navigation system (see Appendix B). The ease of use was the ease with which the drivers understood and executed the navigation instructions when using each navigation system. The level of distraction was the extent to which use of the navigation system interfered with the performance of the primary task of driving. The preference was used to indicate which navigation system the drivers preferred using during the drives. The ease of use and level of distraction had five levels (1-5). The ease of use levels were 1 – very difficult, 2 – a bit difficult, 3 – can’t say, 4 – easy and 5 – very easy. The levels of distraction were 1 – not distracting at all, 2 – a little distracting, 3 – can’t say, 4 – distracting and 5 – very distracting. The overall rankings had three levels (1 – best, 2 – second best and 3 – worst).

7.7 THE DESIGN OF THE SCENARIOS

There were two types of scenarios used in the experiment; the navigation system scenarios and driving environment scenarios. For each of the navigation system scenarios, there was a different conformity; the virtual car was a conformal head-up display, arrow head-up display was a non-conformal head-up display and vehicle satellite navigation system was a non-conformal head-down display. Also, each of the navigation systems were mocked up based on relation to their real world counterparts. For instance, the vehicle satellite navigation system design was modelled against a TomTom satellite navigation device which used a visual map and audio commands for presenting the navigation instructions. The arrow head-up display design was modelled against BMW’s 2012 M6 head-up display. The virtual car head-up display design was modelled against the view of a Toyota Camry 2007.

For the driving environment scenarios, there was a different route in an urban setting used for each of the navigation systems to reduce the learning effect of the routes. Each of the routes were designed to have the same complexity levels e.g. pedestrian activity and medium vehicle traffic density where the vehicles were travelling at a constant speed of 40mph. They would slow down and stop on approaching a red traffic light. The routes had five correct turns in total (apart from other turns on the roads) which would be followed to reach the destination. The driver's ability to follow these correct turns were examined to determine whether there would be any impact on navigation performance due to a change in the navigation interface. For each correct turn missed, the driver's navigation success rate was negatively affected. There were differences in the routes design e.g. two routes required the drivers to take two left turns and three right turns while the third route required the drivers to take three left turns and two right turns. Also, the sequence of the turn directions was varied to reduce the drivers' anticipation of the direction of turn. Furthermore, use of the navigation interfaces was counter-balanced amongst the drivers for each scenario of the simulated environments. It was anticipated that the average time it would take for each drive is about 10 minutes. The routes were designed with this time in mind for safety reasons because of the number of drives which the drivers would make.

7.8 THE DATA ANALYSIS METHODS

The data collected by the simulator software on speed, lane deviation and gap allocation, the numerical data from the video recordings on success rates in the tasks performed and ratings from the NASA-TLX were statistically analyzed using a repeated measures one-way ANOVA (Analysis of Variance) test which had sphericity assumed to check for differences between the means. If there were differences observed between the means of the measured variables, then it would be suggested that a change in navigation interface caused the difference. If there is no difference observed between the means of the measured variables, then it would be suggested that a change in navigation interface did not cause any difference.

7.9 THE EXPERIMENTAL HYPOTHESES

There are several null and alternative hypotheses which would be examined after a change in navigation interface is made. A significance value of $p < 0.05$ is used in this experiment. The hypotheses are outlined as follows:

Hypothesis 1: Impact on speed

H_0: No significant difference; H_1: Significant difference.

Hypothesis 2: Impact on lateral lane position

H_0: No significant difference; H_1: Significant difference.

Hypothesis 3: Impact on gap allocation to vehicles ahead in the lane

H_0: No significant difference; H_1: Significant difference.

Hypothesis 4: Impact on navigation performance

H_0: No significant difference; H_1: Significant difference.

Hypothesis 5: Impact on detection of peripheral object

H_0: No significant difference; H_1: Significant difference.

Hypothesis 6: Impact on reaction times to pressing the button in peripheral detection task

H_0: No significant difference; H_1: Significant difference.

Hypothesis 7: Impact on the use of indicator

H_0: No significant difference; H_1: Significant difference.

Hypothesis 8: Impact on ratings in the questionnaire

H_0: No significant difference; H_1: Significant difference.

7.10 RESULTS

The results of the experiment are outlined as follows:

7.10.1 MEAN SPEED

There was a significant difference in the mean speeds obtained after a change in the navigation systems was made (F (2, 58) = 130.394, p = .000). Bonferroni post hoc test revealed a significant difference in the mean speed comparing all the navigation systems: virtual car head-up display vs. arrow head-up display (29.5 vs. 32.3 mph) (p = 0.000), arrow head-up display vs. vehicle satellite navigation system (32.3 vs. 27.5 mph) (p = .000) and virtual car head-up display vs. vehicle satellite navigation system (29.5 vs. 27.5 mph) (p = 0.000). It was concluded that a change in the navigation systems had a significant effect on the speed of the drivers. Thus, the null hypothesis was rejected. The mean speeds with standard deviation bars are shown in Figure 7.6.

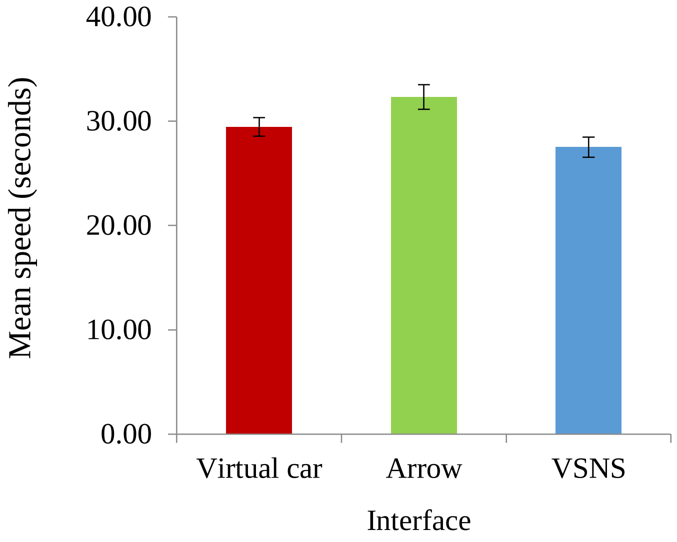


Figure 7.6: Mean speed

7.10.2 MEAN STANDARD DEVIATION IN LATERAL LANE

There was no significant difference in the mean standard deviation of lateral lane position obtained after a change in the navigation system was made (F (2, 58) = 0.796, p = .456). Also, there was no significant difference in the mean lateral lane position between the virtual car head-up display (8.4 feet) (p = .485), arrow head-up display (8.5 feet) (p = 1.000) and vehicle satellite navigation system (8.5 feet) (p = 1.000). It was concluded that a change in the navigation systems did not have any significant effect on the lateral lane position of the drivers. Therefore, the alternative hypothesis was rejected.

7.10.3 MEAN GAP ALLOCATION TO VEHICLES AHEAD IN THE LANE

There was a significant difference in the mean gap allocation to vehicles ahead in the lane obtained after a change in the navigation systems was made (F (2, 58) = 41.369, p = .000). Bonferroni post hoc test revealed a significant difference in the mean gap allocation comparing the virtual car head-up display vs. arrow head-up display (186.4 vs. 279.2 feet) (p = .000) and arrow head-up display vs.

vehicle satellite navigation system (279.2 vs. 167.1 feet) (p = .000). There was no significant difference comparing the virtual car head-up display vs. vehicle satellite navigation system (186.4 vs. 167.1 feet) (p = .482). It was concluded that a change in the navigation systems had a significant effect on the drivers' gap allocation to vehicles ahead in the lane. Therefore, the null hypothesis was rejected. The mean gap allocation with standard deviation bars are shown in Figure 7.7.

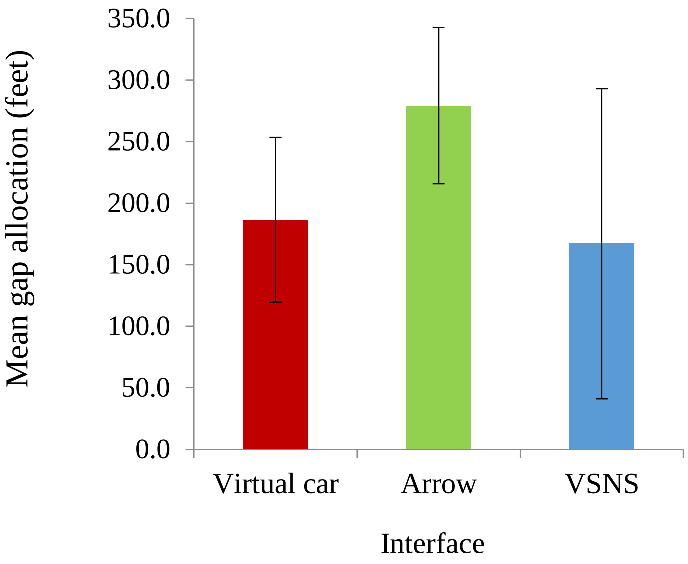


Figure 7.7: Mean gap allocation

7.10.4 MEAN NAVIGATION SUCCESS RATES

There was a significant difference in the mean navigation success rates obtained after a change in the navigation systems was made: (F (2, 58) = 36.25, p = .000). With the virtual car and arrow head-up displays, the drivers took all the correct turns which indicated a mean navigation success rate of 100% whilst for the vehicle satellite navigation system, the mean navigation success rate obtained was 80%. Bonferroni post hoc test revealed a significant difference in the mean navigation success rates comparing the virtual car head-up display vs. vehicle satellite navigation system (100 vs. 80%) (p = .000) and arrow head-up display vs. vehicle satellite navigation system (100 vs. 80%) (p = .000). It was concluded that a change in the navigation systems had a significant effect on the drivers' navigation performance. Therefore, the null hypothesis was rejected. The mean navigation success rates with standard deviation bars are shown in Figure 7.8.

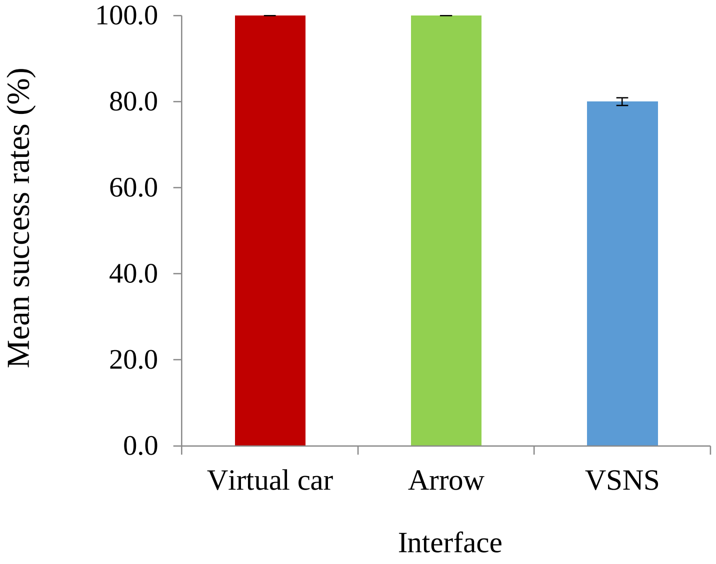


Figure 7.8: Mean navigation success rates

7.10.5 MEAN GLANCE FREQUENCIES

There was a significant difference in the mean glance frequencies obtained after a change in the navigation systems was made: (F (2, 58) = 258.073, p = .000). There were no glances made away from the forward road scene with the virtual car and arrow head-up displays but with the vehicle satellite navigation system there were 42 glances (minimum: 17, maximum: 75). Bonferroni post hoc test revealed a significant difference in the mean glance frequency comparing the virtual car head-up display vs. vehicle satellite navigation system (0 vs. 42) (p = .000) and arrow head-up display vs. vehicle satellite navigation system (0 vs. 42) (p = .000). It was concluded that a change in the navigation systems had a significant effect on the drivers' mean glance frequencies away from the road scene.

7.10.6 MEAN GLANCE DURATIONS

There was a significant difference in the mean duration of glances away from the road obtained after a change in the navigation systems was made: (F (2, 58) = 233.16, p = .000). The mean glance durations with the virtual car and arrow head-up displays was 0 seconds but with the satellite vehicle navigation system, there was a mean glance duration of 25.13 seconds (minimum: 7 seconds, maximum: 43.5 seconds). Bonferroni post hoc test revealed a significant difference in the mean navigation success rates comparing the virtual car head-up display vs. vehicle satellite navigation system (0 vs. 25.13 seconds) (p = .000) and arrow head-up display vs. vehicle satellite navigation system (0 vs. 25.13 seconds) (p = .000). It was concluded that a change in the navigation systems had a significant effect on the drivers' mean glance durations away from the road scene.

7.10.7 MEAN REACTION TIMES TO PRESSING BUTTON IN PDT

There was no significant difference in the mean reaction times to pressing the button in the peripheral detection task obtained after a change in the navigation system was made: (F (2, 58) = 1.124, p = 0.332). With the virtual car head-up display the mean time for pressing the button was 1.14 seconds, arrow head-up display 1.23 seconds and vehicle satellite navigation system 1.30 seconds. It was concluded that a change in the navigation systems did not have a significant impact on the drivers' reaction times to pressing the button in the peripheral detection task. Therefore, the alternative hypothesis was rejected.

7.10.8 MEAN SUCCESS RATES IN DETECTING THE PERIPHERAL OBJECT

There was no significant difference in the mean success rates in detecting the peripheral object obtained after a change in the navigation systems was made: (F (2, 58) = 0.910, p = 0.408). With the virtual car head-up display, the mean success rate in detecting the peripheral object was 4.9 (98%), arrow head-up display 4.8 (96%) and vehicle satellite navigation system 4.7 (94%). It was concluded that a change in the navigation system did not have any significant effect on the drivers' detection of the peripheral object and so the alternative hypothesis was rejected.

7.10.9 MEAN SUCCESS RATES IN INDICATING

There was a significant difference in the mean success rates in indicating obtained after a change in the navigation system was made (F (2, 58) = 42.547, p = .000). With the virtual car head-up display, the mean success rates in indicating was 100% (5), arrow head-up display was 60% (3) and vehicle satellite navigation system 58% (2.9). As a result the null hypothesis was rejected. The mean success rates with standard deviation bars are shown in Figure 7.9.

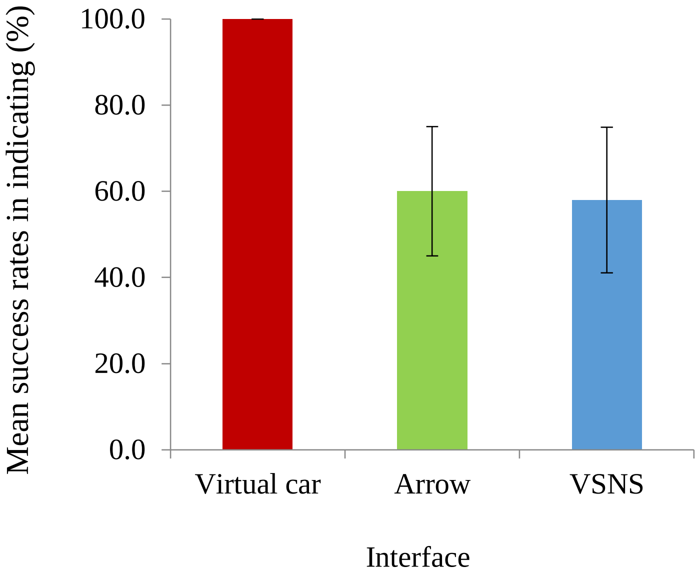


Figure 7.9: Mean success rates in indicating

7.10.10 SUBJECTIVE RATINGS IN THE QUESTIONNAIRE

The ratings provided in the NASA-TLX are as follows:

Mean physical demand

There was a significant difference in the mean physical demand obtained after a change in the navigation systems was made: (F (2, 58) = 4.964, p = 0.01). The mean physical demand with the virtual car head-up display was 2.13, arrow head-up display was 2.10 and vehicle navigation system was 2.37. Bonferroni post hoc test revealed that there was no significant difference in the mean physical demand comparing the virtual car head-up display vs. arrow head-up display (2.13 vs. 2.10) (p = 1.000) and virtual car head-up display vs. vehicle satellite navigation system (2.13 vs. 2.37) (p = .097). However, there was a significant difference comparing the arrow head-up display vs. vehicle navigation system (2.10 vs. 2.37) (p = 0.009). It was concluded that a change in the navigation systems had a significant effect on the drivers' perceived physical demand of the tasks. The mean physical demands are shown in Figure 7.10.

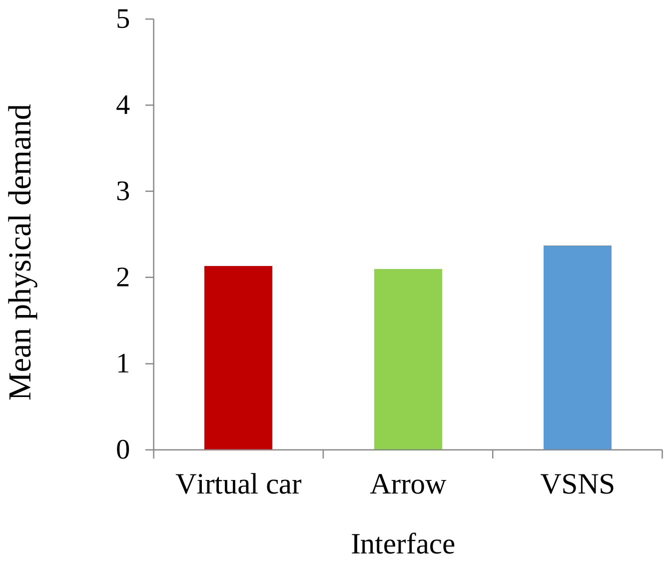


Figure 7.10: Mean physical demand

Mean mental demand

There was a significant difference in the mean mental demand obtained after a change in the navigation systems was made: (F (2, 58) = 9.637, p = .000). The mean mental demand with the virtual car head-up display was 2.23, arrow head-up display was 2.50 and vehicle satellite navigation system was 2.80. Bonferroni post hoc test revealed that there was a significant difference in the mean mental demand comparing the virtual car head-up display vs. arrow head-up display (2.23 vs. 2.50) (p = 0.027) and virtual car head-up display vs. vehicle satellite navigation system (2.23 vs. 2.80) (p = 0.002). However, there was no significant difference comparing the arrow head-up display vs. vehicle satellite navigation system (2.50 vs. 2.80) (p = 0.110). It was concluded that a change in the navigation systems had a significant effect on the drivers' perceived mental demand of the tasks. The mean mental demands are shown in Figure 7.11.

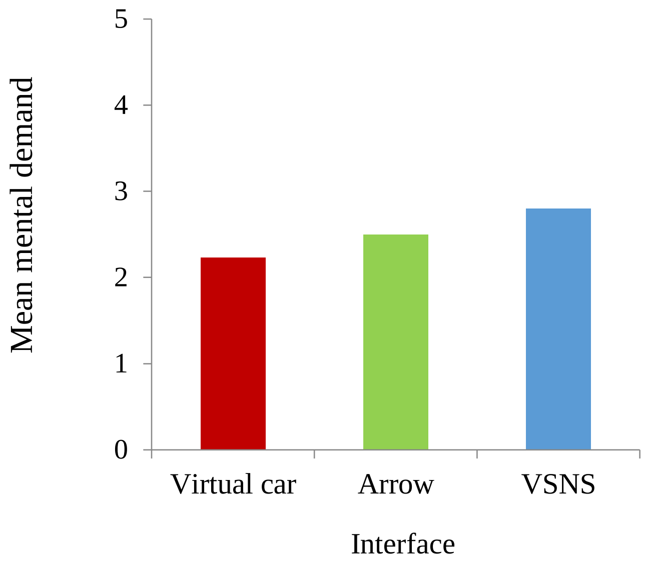


Figure 7.11: Mean mental demand

Mean temporal demand

There was no significant difference in the mean temporal demand obtained after a change in the navigation systems was made: (F (2, 58) = 2.725, p = 0.074). The mean temporal demand with the virtual car head-up display was 2.10, arrow head-up display was 2.00 and vehicle satellite navigation system was 2.30. It was concluded that a change in the navigation systems did not have a significant effect on the drivers' perceived temporal demand of the tasks.

Mean effort

There was no significant difference in the mean effort obtained after a change in the navigation systems was made: (F (2, 58) = 1.000, p = 0.374). The mean effort with the virtual car head-up display was 2.97, arrow head-up display was 2.97 and vehicle satellite navigation system was 3.03. It was concluded that a change in the navigation systems had did not have a significant effect on the drivers' perceived effort during the tasks.

Mean frustration

There was a significant difference in the mean frustration obtained after a change in the navigation systems was made: (F (2, 58) = 6.055, p = 0.004). The mean frustration with the virtual car head-up display was 2.10, arrow head-up display was 2.30 and vehicle satellite navigation system was 2.60. Bonferroni post hoc test revealed that there was no significant difference in the mean temporal demand comparing the virtual car head-up display vs. arrow head-up display (2.10 vs. 2.30) (p = 0.330) and arrow head-up display vs. vehicle satellite navigation system (2.30 vs. 2.60) (p = .213), However, there was a significant difference comparing the virtual car head-up display vs. vehicle satellite navigation system (2.10 vs. 2.60) (p = 0.007). It was concluded that a change in the navigation systems had a significant effect on the drivers' perceived frustration in performing the tasks. The mean frustrations are shown in Figure 7.12.

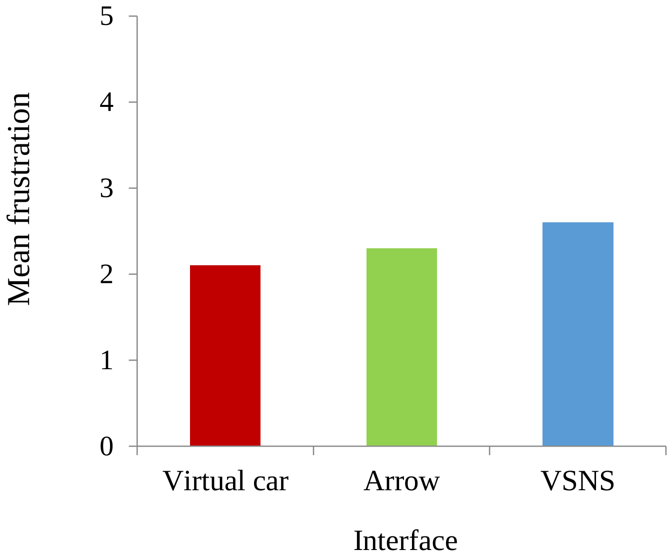


Figure 7.12: Mean frustration

Mean performance

There was no significant difference in the mean performance obtained after a change in the navigation systems was made: (F (2, 58) = 1.586, p = 0.214). The mean performance with the virtual car head-up display was 3.7, arrow head-up display was 3.77 and vehicle satellite navigation system was 3.57. It was concluded that a change in the navigation systems did not have a significant effect on the drivers' perceived performance levels during the tasks.

The other ratings in the questionnaire are provided as follows:

Mean ease of use

There was a significant difference in the mean ease of use obtained after a change in the navigation systems was made: (F (2, 58) = 48.012, p = .000). The mean ease of use with the virtual car head-up display was 4.03, arrow head-up display was 3.63 and vehicle satellite navigation system was 2.73. Bonferroni post hoc test revealed that there was a significant difference in the mean ease of use comparing the virtual car head-up display vs. arrow head-up display (4.03 vs. 3.63) (p = 0.024), virtual car head-up display vs. vehicle satellite navigation system (4.03 vs. 3.63) (p = .000), arrow head-up display vs. vehicle satellite navigation system (3.63 vs. 2.73) (p = .000). It was concluded that a change in the navigation systems had a significant effect on the drivers' perceived ease of use of the navigation systems in performing the tasks. The mean ease of use values are shown in Figure 7.13.

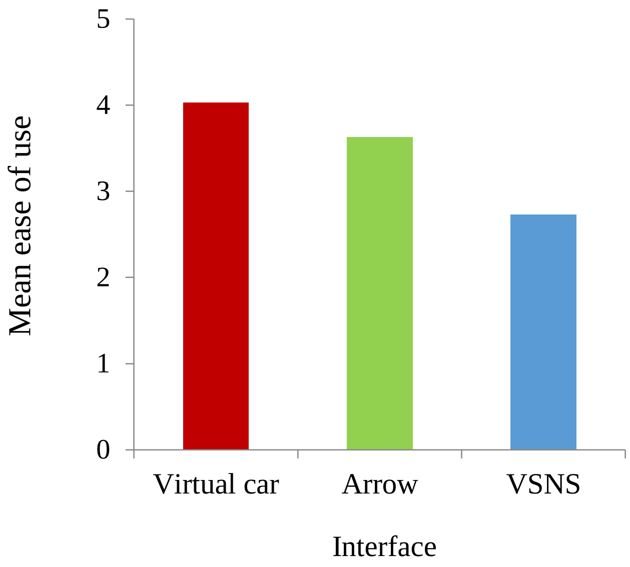


Figure 7.13: Mean ease of use

Mean level of distraction

There was a significant difference in the mean level of distraction obtained after a change in the navigation systems was made: (F (2, 58) = 47.88, p = .000). The mean level of distraction with the virtual car head-up display was 1.57, arrow head-up display was 2.20 and vehicle satellite navigation system was 3.20. Bonferroni post hoc test revealed that there was a significant difference in the mean level of distraction comparing the virtual car head-up display vs. arrow head-up display (1.57 vs. 2.20) (p = .000), virtual car head-up display vs. vehicle satellite navigation system (2.20 vs. 3.20) (p = .000), arrow head-up display vs. vehicle satellite navigation system (2.20 vs. 3.20) (p = .000). It was concluded that a change in the navigation systems had a significant effect on the drivers' perceived level of distraction during the tasks. The mean levels of distraction are shown in Figure 7.14.

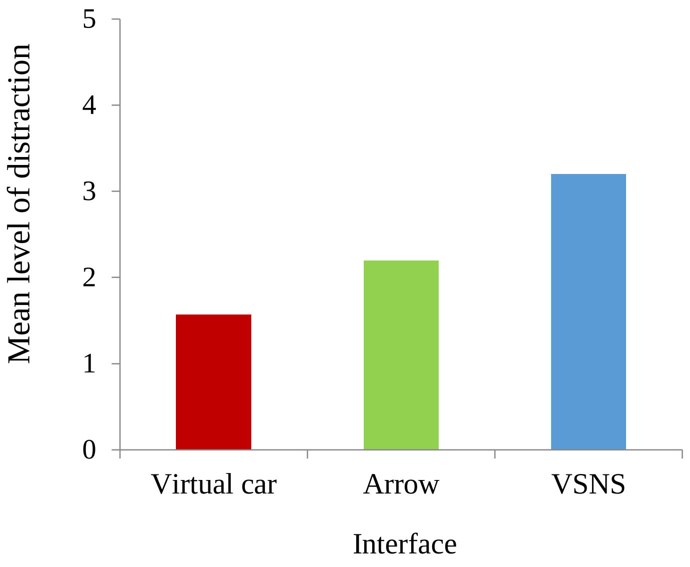


Figure 7.14: Mean level of distraction

Preference of the navigation systems

Eighteen drivers rated the virtual car head-up display as their preferred navigation system during the tasks, ten rated the arrow head-up display as their preferred navigation system while two rated the vehicle navigation system as their preferred navigation system. These are shown in Figure 7.15.

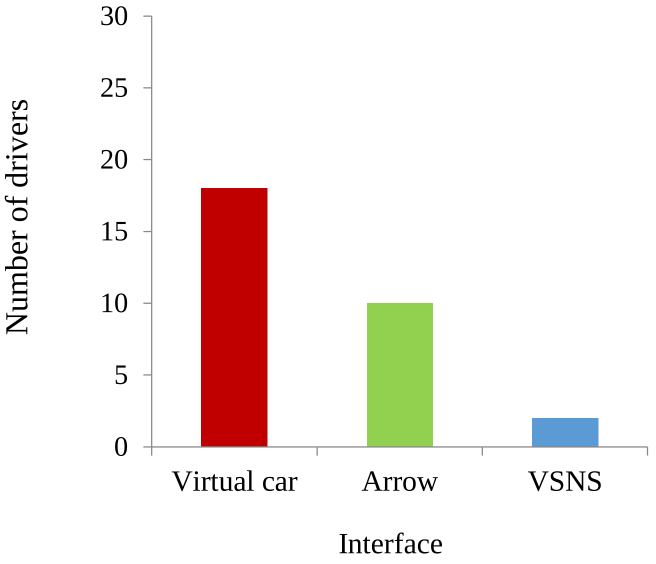


Figure 7.15: Navigation system preferences

7.11 DISCUSSION

The findings from the experiment suggest that the use of the virtual car head-up display was associated with less workload demands and risk of distraction when compared with the arrow head-up display and vehicle satellite navigation system. This may have been supported by the fact that, for example, from a cognitive perspective, the drivers would have not been required to translate the navigation instructions which were provided by the virtual car into actions which were required for navigation. They only had to look and replicate the actions of the virtual car, but not with significant visual demand which would detract them from the surrounding environment. This was found to support better driving e.g. deviating least in the lane without driving too slowly. Also, the values which were obtained for executing the indicating instruction suggested that the virtual car head-up display was better suited for allowing the drivers to indicate their turn direction which is vital for safe driving. With the other navigation systems, this was not always the case as on several occasions the drivers failed to indicate while driving. This highlights positive safety implications concerning the use of the virtual car head-up display as it can support the execution of safe practices whilst driving on the road.

The different mechanisms which were used for instructing the drivers may have affected the task difficulty. For example, there is more visual requirement for using the virtual car when compared with the cognitive aspect. This means that drivers would be less affected when making cognitive decisions whilst driving compared to the visual aspect of its use. Despite this, the virtual car was still able to support a high visual attention to the tasks the drivers performed e.g. lane keeping, peripheral detection, speeding, gap allocation etc. This contrasted the use of the arrow head-up display and vehicle satellite navigation system where findings suggested there were high visual and cognitive demands from the interfaces because the drivers had to process the information which they observed before making decisions.

The findings also indicated that there were less detection rates and more time taken to react to situations in the environment when compared with the virtual car head-up display. There was the least deviation in the lane with the virtual car head-up display which suggested there was less attention to the steering wheel angle with the arrow head-up display and vehicle satellite navigation systems. Also, there was a slower mean speed which was recorded for the vehicle navigation system when compared with the virtual car head-up display. This was interpreted as the vehicle satellite navigation system affecting the driver's interpretation of the task more than the virtual car head-up display. Furthermore, concerning the arrow head-up display, the gap allocation values which were obtained suggested that reading information on the windshield where there was visual acuity required can cause drivers to leave considerable gaps ahead on the road. The information may be illegible over another vehicle in front and so drivers may leave gaps to allow them read the information and make specific decisions.

With the virtual car image collimated in the driver's field of view, there was the need to accommodate the virtual car and background scene to support optimal performance. However, it can be seen that when compared with the arrow head-up display, the virtual car head-up display tackles the accommodation problem more efficiently and allows better awareness of events in the road scene which was evident in the higher performance values in the peripheral detection task. The conformal nature of the virtual car head-up display would have reduced the need for the drivers to distinguish the virtual car image from the surrounding environment when visualizing the field of view because the virtual car was aligned with the simulated environment. The outcome was that the highest rate for detecting the peripheral object in the peripheral detection task was obtained. It was suggested that the value associated with the arrow head-up display may have been obtained because the arrow head-up display was drawing the drivers' attention inwards to the windshield when they were looking at the navigation information. This would have reduced their performance in the peripheral detection task when compared with the virtual car head-up display.

The different locations for the navigation systems resulted in different visual behaviors. For example, the head-up displays were found to support more visual attention on the forward road scene when compared with the vehicle satellite navigation system which was associated with a number of glances from the road scene. These glances were associated with the highest impact on the drivers' navigation performance and peripheral detection. It was not very clear though whether with the virtual car and arrow head-up displays the drivers were actually looking at the road or at the display. The exact location of the focal point of the driver's eyes could be measured using direct measures e.g. eye tracking which was not used in this experiment. This can be looked at in future research to evaluate the impact which these types of head-up display can have on the driver's visual workload.

It was also important to identify the trade-offs between having information displayed on the windshield and on the dashboard. With the head-up displays, it was found that displaying the information in the driver’s field of view allowed drivers to focus their attention on the forward road which can be attributed to the higher success rates and rapid response times in detecting the peripheral object. Also, this enhanced their success rates in the navigation task. However, when the drivers do not have control over whether the head-up display information should be present in their field of view then it is possible that drivers may find use of the head-up displays inconveniencing particularly under high workload when they desire to turn off the head-up display information. It may be unlikely that the drivers would turn off the head-up display because they would need the information in order to make decisions. However, if they do turn it off, they may be distracted by having to turn it on and off. This can increase the risk of attention capture and distraction. With the vehicle satellite navigation system, the risk of attention capture due to having information in the field of view was less of a concern when compared with the head-up displays because the visual interface was located on the dashboard. The drivers could choose not to look at the visual display and just focus only on the voice commands. However, the experiment did show that the drivers looked at the vehicle satellite navigation system interface on the dashboard which led to periods where they took their eyes off the road.

The subjective ratings which were obtained from the drivers led to suggestions that they favored the virtual car head-up display over the arrow head-up display and vehicle satellite navigation system. The lower ratings for mental demand suggested that the drivers found the cognitive workload associated with the virtual car lesser when compared with the arrow head-up display and vehicle satellite navigation system. It is suggested that based on these ratings the understanding of the instructions with the virtual car head-up display was better and the virtual car can be said to have lesser cognitive demands when compared with the arrow head-up display and vehicle satellite navigation system. Also, the performance ratings suggested that the drivers were able to perform their tasks better with the virtual car head-up display when compared with the arrow head-up display and vehicle satellite navigation system because of the alignment of its behavior with real world driving. The suggestion is that drivers are less likely to make navigation errors and affect safety of other road users when they see the turn instructions being shown in the particular direction they should be made. This means that there are positive implications concerning the virtual car head-up display for improving the driver's spatial orientation in different directions of the road.

For the ease of use, the virtual car head-up display was rated as the easiest navigation system to use. This can be associated with the types of mechanisms used by the virtual car to provide the navigation instructions which are familiar to drivers such that the drivers may have simply recalled the turn left or go straight or indicate right instructions from memory instead of process them from scratch. The preferential ratings suggested that the virtual car head-up display was the most liked navigation system which has positive implications regarding the willingness of drivers to accept and use the system for navigation.

7.12 SUMMARY

The experiment findings suggested that the virtual car head-up display was associated with less workload demands and risk of distraction when compared with the arrow head-up display and vehicle satellite navigation system. This is a major contribution to the research as it outlines the benefits of the virtual car head-up display over prototypes of its existing counterparts. The experiment showed that the conformal nature of the virtual car head-up display impacted the least on the detection of peripheral objects in the surrounding environment because the drivers were not compelled to distinguish the virtual car from the background road scene. The drivers indicated that they found the virtual car head-up display easy to use and less distracting when compared with the arrow head-up display and vehicle satellite navigation system. This was linked with them having to recall the information which they were familiar with from memory instead of processing the instructions from scratch such as those issued by the arrow head-up display and vehicle satellite navigation system. This led to faster times and higher success rates in the tasks which were assigned to them in the experiment. The drivers can also allocate more time and attention to performing the primary tasks of driving because the instructions were found to fit more with the navigation practices employed in real world driving when compared with the mechanisms which were employed by the arrow head-up display and vehicle satellite navigation systems. The overall implications for the virtual car head-up display is that if fully developed it can be a safer alternative which can cause less workload and risk of distraction for drivers.

CHAPTER

8

DISCUSSION

8.1 INTRODUCTION

The focus of this chapter is to provide an overall discussion on the key results to have emerged from this research. These would be channeled towards enhancing knowledge in the design of vehicle satellite navigation systems. There has been analysis and discussions provided for each chapter previously therefore, this chapter does not go into discussing specific results or data at a detailed level. Instead, there is a synthesis of results which would lead to conclusions presented in the final chapter of this thesis. To proceed with this, the research problem would be revisited and the concerns which motivated the research would be outlined. Issues of importance would also be discussed concerning the acceptance of new technology into the vehicle to aid the accomplishment of specific tasks for the drivers. Thereafter, the results from the research would be discussed in relation to existing knowledge in the field. Also, the implications concerning the virtual car head-up display for navigation systems design would be examined. Finally, there would be an outline of the opportunities for future work.

8.2 THE RESEARCH PROBLEM REVISITED

The issues of increase in driver workload and distraction are areas which are being researched. Technological advancements which have been provided to drivers have been associated with increased workload causation which often leads to distraction. Particularly, vehicle satellite navigation systems have been associated with increased workload demands because they are often located away from the driver’s field of view and this promotes glances away from the road scene. Also, the mechanisms which they employ cause drivers to undertake additional work of translating the navigation instructions before executing them in the real world. This can distract the driver from allocating attention to perform the primary driving tasks. There have been alternative ways of presenting information to the driver that have been explored e.g. by shifting the location of the information to the windshield through the use of head-up displays. Head-up displays allow the driver to take in secondary information whilst driving thereby helping to increase the driver’s ability to simultaneously perform both sets of tasks. However, head-up displays have been associated with some issues such as misaccommodation, visual clutter and attention capture. These have impacts on the performance of the primary driving tasks. It can be useful to explore alternative solutions which address these issues so that it could be possible for drivers to better perform their tasks with greater efficiency.

8.3 PROVIDING SOLUTIONS THROUGH DESIGN

Design should continuously explore ways of tackling the issues of workload and distraction associated with existing navigation systems in vehicles in order to provide solutions for drivers which would improve the level of safety and performance while driving. There can be focus on providing systems which reduce the work of translation which is implicated in voice commands and visual maps employed by vehicle satellite navigation systems. Also, the issues with head-up displays can be examined in more depth to deal with the issues and enhance their design so that they can be more usable in the navigation task.

In this research there has been design work done to explore the design concept of a virtual car head-up display which has the potentials to tackle the work of translating instructions by embedding the navigation instructions which it uses in real world driving practices. The design process was shaped by examining the real world organization and execution of the navigation task by drivers themselves who would be the eventual users of this system to understand the contexts to design for. This approach has been quite useful to adopt in this research because it has enabled several comparisons to be made between how the virtual car head-up display behaves and how real world vehicles behave. It is based upon the comparisons that several suggestions on how the virtual car head-up display would be able to deal with the issues highlighted with the existing navigation systems have been made.

8.4 IMPLICATIONS OF THE VIRTUAL CAR HEAD-UP DISPLAY FOR DESIGN

The virtual car head-up display is a conformal scene augmentation which is collimated at optical depth in the real world so that it appears as a part of the real world whilst presenting the required navigation instructions to drivers. The impact of collimation as described by Weintraub and Ensing (1992) is to support an outward direction of focus to the external world so that there is more attention on events which occur outside the vehicle. This has positive safety implications for the driver. The virtual car head-up display employs this technique so that even though the virtual car is displayed on the windshield, the drivers are still able to interact with the virtual car as though it exists in the real world. They follow the car as though it is a lead vehicle which means that there is attention focused on what the virtual car does in the external environment instead of on the windshield in the driver’s vehicle. Hence, it can be suggested based on how the drivers were able to follow the virtual car on the road in the simulator studies in this research, that collimating the virtual car in the real world would cause focus to be pushed outwards to the external world so that drivers can focus their attention in the real world rather than on the information contained on the windshield. This aligns with the argument of Weintraub and Ensing (1992). The virtual car head-up display can be described as an example of how similar head-up displays can be used to address the misaccommodation problem.

Furthermore, by employing real world driving practices in a familiar car representation so that the ways in which the navigation instructions are presented to drivers align with the contexts of real world driving, it is possible to tackle the issues of translation for the navigation instructions which is associated with vehicle satellite navigation systems. The drivers would not be involved in performing cognitive processing before the navigation instructions are executed, instead they would simply look and replicate the actions of the virtual car. This would make following the virtual car a non-time consuming task where there is little attention required to perform specific actions. This means that drivers can have more time and attention to focus on execution of the primary tasks. The implication here is that the virtual car would require less of the driver’s cognitive resources and can thus be regarded as a low-demand cognitive interface. And even though the design of the virtual car would imply that it has more visual impacts on the driver than cognitive, such impacts are not likely to be very significant because the way the virtual car behaves when displayed in the driver’s field of view corresponds with what drivers see in their everyday driving with other vehicles. They consciously or subconsciously follow other vehicles which perform the set of actions utilized by the virtual car head-up display. Therefore it would be very easy for them to easily adapt to the virtual car head-up display and follow it on the road.

In essence, the virtual car head-up display fleshes out a lot of the more or less “unnecessary” details which drivers are provided with by other navigation systems to reduce the amount of attention required and focuses more of the driver’s attention on performance of the primary driving tasks. This is because what most drivers may simply need to know from a navigation system is how they would get to their destination i.e. from point A to B. It may be useful to know other aspects e.g. the distance to reach a destination but the consideration would be how much value the added information would provide for the driver. And when more information is added to the head-up display thereby increasing its complexity, Burnett and Donkor (2012) suggest that this can have an effect on the driver’s performance. Thus, from a safety perspective, the lesser the amount of information which is provided in the driver’s field of view, the less clutter would be involved as well as less information to compete with the view of the external world for the driver.

The virtual car head-up display is perhaps the first in the range of navigation systems in vehicles which seeks to augment the driver’s view with this car object to provide navigation instructions. The reason behind this is to provide an interface to drivers which would support natural driving behavior thereby making the tasks involved much easier to understand and perform. By aligning the navigation instructions with the primary task of driving, it can be possible that similar types of navigation systems would not interfere with the execution of the primary tasks but instead would enhance their accomplishment e.g. indicating, turning, positioning in lanes etc. Such types of systems can become embedded within the primary tasks themselves instead of the way which the use of most navigation systems is considered secondary to the primary tasks. This can reduce the extent of interference with the primary tasks of driving. Also, the virtual car design concept provides evidence which can help to shape the design of future navigation systems which intend to adopt a similar design approach regarding how it utilizes information which is obtained from the real world contexts to support natural driving behaviors in a new interface. In this research, it can be seen how the design evolved from the car following concept in the real world to using the information obtained in that study to produce an artefact which can be taken back to the real world and used to support drivers with very similar needs.

In terms of the findings from the empirical work, the findings suggest that the virtual car was able to guide the drivers along the routes to their intended destination which confirms its usability as a navigation tool. There are wider implications of this in certain areas of driving. For example, because the virtual car is a very graphical navigation interface which appears out on the road, it can be used to train new drivers on how to drive. They are not only told what to do but they are also shown how to do it by the virtual car. The new drivers would look and replicate the actions of the virtual car which can complement the instructions from a driving instructor. The virtual car would be able to support them in the different aspects of driving e.g. when to indicate, turn, position in a lane etc. which can make it quicker for drivers to learn what they need to do during their training lessons. Furthermore, it can be useful in city driving where there are a lot of turns to take and drivers need to have a good orientation of where they need to turn in respect to the directions they are getting from a navigation system e.g. to turn left or right. This relates to their spatial orientation such that rather than wonder where a left turn is and possibly end up turning right, the virtual car effectively shows them the direction of the turn. Confirming the direction of turn can help drivers make less navigation errors which would improve their utilization of resources while driving e.g. time, fuel and energy.

From a technical point of view, there may be challenges faced to effectively implement this scene augmentation in the real world in the way which would best reflect the intentions in the concept of the virtual car head-up display. For example, the virtual car would need to align with the real world to use lane markings in providing the required navigation instructions. However, it is likely to be that the position of the virtual car would be reflected by the position of the driver's vehicle and so if the driver's vehicle is not well positioned in the lane, this would also affect the position of the virtual car on the road. This is different from the real world scenario of the design concept where the lead vehicle exists independently of the trailing driver allowing the vehicle to be positioned appropriately in the lane. Hence, the implementation of this concept in vehicles needs to be done with intelligent systems which would be able to assist the drivers in achieving optimal performance where the driver's field of view of the real world is tracked and the virtual car positioned to fit within the appropriate lanes.

From a behavioral point of view, there was the issue noticed in some of the studies where it appeared as though the drivers were driving to the virtual car in the field of view rather than the real world. This caused them to leave gaps in front of the vehicle while driving. There should be careful thought put into the implementation of the virtual car in the real world because it could affect behavior on the road. Given the highly visual nature of the virtual car head-up display, there is the possible safety impact which this can have on the driver in terms of visual tunneling. It could be possible that some drivers may blindly follow the virtual car in the field of view and may not allocate enough attention to events which are taking place in the surrounding environment. This can affect their detection of critical events which occur. An aspect where this might be of significance would be when drivers are navigating in traffic. It would be important that drivers do not try to fit the virtual car in between their vehicle and another vehicle in front as this could increase the gaps between vehicles and potentially cause traffic to build. The virtual car should be designed to allow the driver know that the virtual car would not interact with traffic in the real world thereby making the driver more responsible for driving in traffic. Also, the issue of visual tunneling can affect driving in traffic because if the driver is visually tunneled to the virtual car in front then it is possible that the driver may not detect when other vehicles are switching lanes or could miss warning information on road signs.

The driver may also face the issue of cognitive tunneling when driving to the car in front. This is because the driver may be focused on trying to determine what would be the next set of actions which would be displayed by the car and could fail to detect critical events which would affect the safety of the vehicle passengers. The inactive state was integrated into the design of the virtual car head-up display to significantly reduce the impact which cognitive tunneling can have on the driver’s allocation of attention to the virtual car so that the driver can focus on the road as a whole. It is anticipated that this would help to reduce the shift in the driver’s attention from the road scene so that there is better performance of the primary driving tasks.

8.5 ACCEPTANCE OF NEW TECHNOLOGY IN THE VEHICLE

Given this new type of interface which would be provided for drivers to use during navigation there is the issue of acceptance which could affect the overall growth of the technology for drivers. In the literature, Regan et al. (2014) discuss the acceptance of new technology and highlight that the acceptance of new technology and systems by drivers is an important area of concern to governments, automotive manufacturers and equipment suppliers especially technology that has significant potential to enhance safety. They describe acceptance in the information technology domain as “the demonstrable willingness within a user group to employ information technology for the tasks it is designed to support”. They suggest that there are complex determinants for user acceptance and derive from the technology itself, from those who use it and from the context which it is implemented. Dillon (2001) and Rogers (1995) mention the characteristics of technology that determine its level of acceptance which include relative advantage over other available tools, compatibility with social practices and norms, complexity in ease of use and learning, ‘trial-ability’ of the technology before use and ‘observability’ – or the extent to which the benefits of the technology are obvious.

Regan et al. (2014) suggest that to be acceptable the new technology must be useful and satisfying to use. If it is not, drivers will not want to have it in which case it will never achieve the intended safety benefit. Also, even if they have the technology, drivers may not use it if it is deemed unacceptable or may not use it in the manner intended by the designer. At worst, they may seek to disable it. Burnett and Diels (in Regan et al. 2014) discuss the impact of new systems for drivers as it relates to providing information to the driver. They indicate that the different types of systems which are afforded to drivers can have impacts on the primary driving tasks (distraction, behavioral adaptation etc.). They highlight the importance of acceptance of new technology by end users for several reasons. The first reason is that systems must be accepted if they are to be used such that the fundamental design goals for a system (safety, driving efficiency and so on) have the potential to be met. The users may want to make use of the new technology if they think that it can make their task to be performed better with less stress. Therefore, the goals for which the technology is provided could be a deciding factor for the acceptance of new technology.

The second reason they mention is that an understanding of acceptance is required when considering the closely related issues of usability and satisfaction. This is because for systems to be accepted, they must be usable and the users must feel satisfied with using them. Else, it would be possible that the users may find it difficult to use and get frustrated with the technology. Also, they may not be satisfied with the level of assistance which they get from the technology and as a result may lose interest in using the technology with time. The third reason is that acceptance is highly relevant to key issues of trust and reliance for in-vehicle technology because when new systems are wholly accepted, trust levels may be overly high and there may be a mismatch between objective and subjective levels of reliability of a system. Burnett and Diels (in Regan et al. 2014) indicate that this could result in complacency (e.g. following instructions from a navigation system when it is inappropriate to do so). Also, that a system which is unacceptable to users may be deemed untrustworthy and may be used in an inappropriate fashion (misuse effects). Burnett and Diels highlighted a study by Forbes (2009) where a trust issue was identified for certain drivers in specific situations. It was highlighted that in the study, there was evidence of overtrust (or complacency) where the drivers saw the relevant road sign/cue but chose to ignore it and favored the navigation instruction. There was also the issue of attention which was identified where the drivers did not believe they saw or processed the relevant road sign/cue. Large and Burnett (2013) considered these issues in a driving simulator context using eye-tracking and they confirmed that drivers would place the blame either on themselves or the surrounding road infrastructure for system acceptance.

The chapter concludes by highlighting that the vehicle often incorporates a social environment when passengers are present or even when communications are conducted with people who are remote or external to the vehicle (e.g. via phone link). It is highlighted that previous research concerning acceptance issues has focused largely on the driver solely as an operator of the vehicle even though in reality, the social context will have a considerable impact on user’s attitudes, behavior and performance with new technology in highly dynamic and complex driving situations. The study which was conducted by Large and Burnett (2013) noted how the presence of passengers affected a driver’s interactions with a navigation system especially as it relates to the acceptance of voice instructions.

The concerns of the authors in relation to the acceptance of new technology is one which should be taken seriously in order to ensure the growth in use of this new virtual car head-up display technology. It would be important that drivers are able to follow the virtual car head-up display in the intended way for which it is designed so that it does not have any impact on the overall safety of the drivers and performance of the primary driving tasks. The issue of acceptance was considered during the design process to ensure that the virtual car could be used by drivers during navigation. The use of instruction mechanisms which are familiar to drivers where what the driver knows would be the focus of the navigation instructions was targeted to ensure that the driver can easily understand the instruction provided within a short period of time. This can help them to accomplish their tasks more efficiently and possibly increase the acceptance of the technology as the design process is driver-centred. The considerations which were accounted for during the design of the virtual car head-up display and the findings from the empirical studies concerning the benefits of the virtual car head-up display over the prototypes of the existing navigation systems are evident in the characteristics highlighted by Dillon (2001) and Rogers (1995). This has led to suggestions that the virtual car head-up display would be acceptable if fully implemented in real world vehicles.

8.6 CONTRIBUTIONS TO RESEARCH

This research has outlined how the voice commands and visual maps which vehicle satellite navigation systems use to instruct drivers can increase the driver's workload and risk of distraction. It has not been a major part of research where there has been focus on how these voice commands can cognitively affect the driver. Whilst most studies conducted with vehicle satellite navigation systems (e.g. Tijerina et al., 2000; Green et al., 1995; Gartner et al., 2002; Burnett and Parkes, 1993) have outlined the usefulness of the voice commands when providing pre-turn information it has not been adequately accounted for how these voice commands affect driver workload. However, in this research, it was found that when listening to a voice command and looking at a visual display on approaching a junction, the drivers failed to detect a peripheral object appearing in the background scene. This shows that cognitively loading tasks can affect peripheral detection of critical events in the background which are important for the safety of the vehicle passengers.

The research has outlined the concept of the virtual car head-up display which utilizes real world navigation practices that are employed in everyday driving by drivers. The virtual car head-up display is designed to fit with the natural contexts of real world navigation so that drivers would be able to explore their real world driving competence and understand the instructions provided based on their familiarity with how the instructions are provided in the real world. This is an aspect of the design concept which existing navigation systems have not adopted yet in their design as they currently employ abstract mechanisms in providing navigation instructions to drivers. Furthermore, the virtual car head-up display has applied the concept of scene augmentation where the virtual car is displayed in the driver’s field of view to appear as part of the outside environment despite being separate from it. It is not well documented whether this scene augmentation has been used in the design of information systems for vehicles and so the virtual car can provide significant information towards how this can be possible.

It is expected that this research which has been conducted with the virtual car would provide more information to the body of knowledge on head-up displays which utilize these techniques in order that researchers can further investigate how they can be improved upon. The virtual car head-up display has been examined for its usability in the navigation context and the findings from this research have shown that the concept is feasible. The research has also shown that it is better to conform the virtual car head-up display to the external road by collimating it at an optical depth so that it appears as part of the external surrounding. There is the potential for the collimation of this car object to help in addressing the issue of misaccommodation which would likely exist between the virtual car head-up display and the real world so that drivers do not find it difficult to accommodate the virtual car and real world in the same space. It would also help in supporting a tailored set of navigation instructions to drivers which supports enhanced navigation decision making and/or performance.

When compared with the prototype of a vehicle satellite navigation system and head-up display it was found that the virtual car head-up display supported better behavior and performances. This shows that the virtual car head-up display has the potential to reduce the driver’s workload and risk of distraction better than these navigation systems. As a result, it would be useful if there is progress made in the development process in order that the virtual car head-up display is fully developed and made available to drivers. Also, more work is expected with the virtual car head-up display to examine various other aspects of its design in the future and these should provide useful contributions to the design of head-up displays. It is predicted that if the virtual car head-up display is eventually implemented in real world vehicles it would be a useful addition to the range of navigation systems which drivers would have at their disposal to receive navigation instructions while driving.

Furthermore, based on the design and evaluation approach utilized in conducting the work of this research, there have been significant benefits which show that by integrating the work practices of users and accounting for them in design, a usable artefact can be designed. The understanding which was obtained after directly observing drivers in their natural contexts was applied in ensuring that the needs of drivers were met in the system to ensure usability in the navigation task. The findings from the research show that from a usability perspective (e.g. in Rosson and Carroll, 2002), the virtual car head-up display design process is a useful approach to consider to design a system which would be effectively used by users in the real world.

8.7 LIMITATIONS OF THE RESEARCH

There were several aspects which this research work could not investigate due to time and the scope of work involved. The following aspects are discussed as limitations for the research.

Effect of simulator on validity of results

The laboratory simulator environment provided a test environment which was safe and allowed the research work to be conducted. However, given that the research was not conducted in a high level driving simulator, there may have been effects which performing the driving task in the simulator would have caused. For example, because there were notable differences between the real world and the simulated environment, the participants may not have displayed their true driving behavior which would have affected the results that were obtained. Also, because the drivers were isolated from their normal driving conditions when placed in the simulator setup, they may have changed their behaviors to adapt to the simulator which would have not reflected their actual driving behaviors. Furthermore, knowledge that there was little risk of harm may have caused the participants to be less safety conscious in the driving simulator environment. The low fidelity of the driving simulator used in the research may have negatively affected the validity of the results obtained e.g. due to controls, realism and features present.

In terms of the visualization of the virtual car which appeared on the virtual road, this may have also affected the behaviors of the drivers because it may have been possible that they perceived the virtual car to be another car which was out on the road due to similarities in the “virtualization” of the cars on the road. This was evident in the gap allocation issue mentioned in the feasibility study where it was possible that the drivers were driving to the virtual car that was in front instead of differentiating between the two information sources. Potentially, this may not be a problem in a real road situation where drivers would be able to distinguish the virtual car from other real world cars.

Furthermore, given that there were no direct measurements of workload and distraction, but instead these were inferred through indirect measures e.g. glancing, peripheral detection, lane deviations and reaction times to events, it is possible to suggest that these may have not adequately accounted for the likely potentials for workload increase and distraction with the navigation systems which were examined. There may have been more evidence to support the claims regarding the potentials for the virtual car head-up display if there were direct measures employed e.g. eye tracking, however, based on the limitations in the time and resources available to conduct this research, it was not possible to evaluate every aspect of the design. Hence, future research can continue with the evaluation of the virtual car head-up display in order to identify whether there would be any change in behavior with a higher level driving simulator.

Scope of participants

A limited number of drivers took part in the experiments and the sample sizes were constrained by available resources. This may have produced insignificant results which over a larger sample size of drivers with various characteristics may change the outcome of the data analysis. Furthermore, the impacts of variables which include age, gender and driving experience were not factored into the design of the experiments. It may be that there are impacts which these variables would have on use of the virtual car head-up display which have not been accounted for in this research. For example, research has been conducted which shows how age and driving experience affects how drivers use in-vehicle systems (Lam, 2002; McKnight and McKnight, 1993; Reed and Green, 1999; Schreiner, Blanco and Hankey, 2004; Shinar et al., 2005). A lot of these studies found that older people have a decreased ability to divide their attention effectively between simultaneous tasks because of their visual and cognitive capacity which means that they are more susceptible to distraction effects of engaging in secondary tasks when compared to younger drivers.

Also, it is possible that young novice drivers would be more vulnerable to effects of distraction when compared to experienced drivers. The literature suggests that inexperienced drivers tend to often lack the driving skills which are necessary to operate and manoeuvre a vehicle using only minimal attention resources which can impact upon their spare attention capacity to devote to secondary non-driving tasks (Regan, Deery, & Triggs, 1998; Williamson, 1999). As a result, it is possible that inexperienced drivers may find it more difficult to divide their attention appropriately between driving and non-driving tasks which can reduce their performance.

Focal plane and distance judgment

When the virtual car is displayed in the driver's field of view as a car which the driver should follow, it may be difficult for the driver to judge the focal plane and distance of the object. This may be due to visual impairments of the driver which would make it difficult to tell where the virtual car actually lies in the real world when an adequate response to the instruction should be provided. The research has not gone in depth to further examine how deep the driver has to focus the virtual car in the field of view because it is possible that if the driver focuses the virtual car on the focal plane of the windshield then this may reintroduce the misaccommodation problem. The research has not taken into consideration the visual attributes of the drivers and so there may be issues for future work to look into.

Personalization of the virtual car

In the design of the virtual car prototype which was used in the testing stage, the virtual car was set to a particular car rather than providing the participants with the option of choosing which type of car they want to use. This helped to keep the research balanced and reduce the amount of work needed to analyze all the changes for different personalization. However, it did not show whether the drivers preferred to use other types of cars. It is possible that the eventual implementation of the virtual car can be made personalized to suit the driver's needs. It would be useful to know how this would affect the driver's workload and risk of distraction, e.g. considering what would happen if drivers want to follow a make of vehicle they own or whether they would want to integrate engine sounds into the virtual car. These may affect the level of attention which the driver would allocate to the virtual car especially if the personalization creates a virtual car with a high distraction potential.

Simulation of the virtual car

The design of the virtual car was designed to suit the design of the environment in the simulator e.g. making turns, going straight and often making a few bends along the way. The real world is much complex than the scenarios which were used in the simulated environment and the prototype designed for the virtual car in this initial testing may be insufficient for real world conditions. The design of the prototype would therefore need to be improved upon taking into consideration the complexity of the real world driving contexts. This is so that it can adhere to the real world and be usable in different navigation contexts to support the driver more effectively.

8.8 OPPORTUNITIES FOR RESEARCH

Whilst there is promise in the design concept of the virtual car head-up display, there are still several aspects which need to be looked into. For example, it would be useful to find out how the virtual car head-up display can be used in a real world navigation context. It would be useful to identify how different contexts in the real world e.g. traffic, illumination, road conditions etc. can affect use of the virtual car head-up display so that this can be better accounted for in the design of a later version of the system.

Also, given that the virtual car head-up display is likely to have more visual impacts on drivers when compared with cognitive impacts it would be useful if there are specific measures employed which directly assess the visual demand associated with the virtual car head-up display. If a visual workload technique e.g. eye tracking is used to assess the visual workload which is imposed on drivers by the virtual car head-up display then it would be possible to say to what extent the virtual car affects the driver’s focus on the forward road.

The characteristics of drivers which were not accounted for in this research can be factored in to future work with the virtual car head-up display to understand how the differences in driver attributes can contribute to varying levels of behavior. This can affect the real world use of the virtual car and so it is important that there is some type of study which looks at this issue more carefully.

Furthermore, having outlined that personalization would be an interesting aspect of the design to consider it would be useful to study the effects which personalization would have on the choice of virtual car used during navigation. There may be factors to consider which arise when drivers want to follow a different type of car e.g. does the choice of car affect the driver’s mood during the drive and how would the different choices made available to the drivers affect their interaction with the car.

Finally, it would be useful to identify a way to distinguish the turn instruction from the lane changing instruction. This can help to enhance the usability of the virtual car head-up display under different navigation situations.

8.9 SUMMARY

This chapter provided a reflection on the key findings to have emerged from the empirical work in this research by synthesizing the results and providing several implications for design. Issues which relate to the acceptance of new technology were discussed. The contributions of the research were outlined along with several opportunities for research. These have led to an outline of several outcomes which would be presented in the final chapter of this thesis.

CHAPTER

9

RESEARCH CONCLUSION

9.1 CONCLUSION

The primary aim of this thesis was to introduce the design concept of a new head-up display which can reduce the additional workload and risk of distraction which is involved in presenting navigation information to drivers when compared with existing navigation systems. There was emphasis on abnegating the work which is involved in translating voice commands and visual maps to situationally meaningful action in the surrounding environment before the instructions are executed. Furthermore, there were issues highlighted with head-up displays which can affect their usability which were considered during the design. The research therefore employed a range of methods to design and evaluate this new design concept of the virtual car head-up display which is introduced in this thesis. Several outcomes were identified from the thesis and these are summarized in the rest of this chapter.

9.2 WORKLOAD AND DISTRACTION WITH NAVIGATION SYSTEMS

This research suggested that workload can play a major role in causing distraction to drivers when they engage with in-vehicle interfaces such as vehicle satellite navigation systems and head-up displays. The distraction can interfere with the driver’s execution of the primary tasks of driving. This is because the distraction arises when there is competition for attention resources which are used to perform other concurrent tasks along with the primary tasks and this causes resource sharing. Given the complex nature of the driving task, a common theme in literature has been to find a solution to the problems which surround driver workload increase and risk of distraction so that the driving task can be made not only safer but also easier to manage. It is possible that an avenue to reduce this potential risk of distraction from the primary tasks would be to manage the amount of information which drivers are exposed to whilst driving so that they can focus their attention on performing the primary tasks of driving.

The different types of workload were examined and the ways in which they can affect the risk of distraction so that these could be factored in the design of future navigation systems provided to drivers. The driving task was identified as a high visual loading task where the driver takes in a huge amount of visual information from the environment to make decisions at quick speed. Hence, it was considered useful to ensure that the visual impacts of systems on the driver are kept to a minimum in order to reduce any interference. For example, from the attentional resource theories examined it was identified that intra-modal tasks often cause high interference between themselves e.g. looking at the road would be affected by looking at a display on the dashboard. Hence, to reduce the impact of distraction on the attention to the forward road it would be useful to reduce the need to share the same attention resources continuously with other simultaneous tasks.

9.3 EXPLORING USER PRACTICES IN DESIGN

It was considered vital that from a design perspective, the contexts of tasks which are to be designed for should be studied directly. Direct observation of accomplishments of tasks would provide a useful understanding of how context affects the task which would not be known if not studied. This would help the designers to design a system which reflects issues in the real world to enhance its usability, satisfaction of use and acceptance. It was important that the design of the navigation interface would take into consideration, the user practices involved in the primary tasks of driving to make the task of navigation easier to understand and accomplish. It was also deemed useful to align the navigation instructions which would be provided to drivers in ways which fit with the accomplishments of the primary tasks of driving in the real world. It was believed that this could help to address the translation problem with voice commands and visual maps associated with existing vehicle satellite navigation systems and head-up displays.

These considerations led to the proposal of the virtual car head-up display which is embedded in the user practices involved in driving so that there is less translation of instructions involved before navigation actions are executed in the real world. The virtual car head-up display design was shaped by an informative field study where an idea was transformed into a design artefact through a series of evaluations. The virtual car head-up display concept was targeted towards designing around the user practices of the driver so that drivers can draw on their familiarity with the instruction mechanisms used by the virtual car based on their driving competence in real world navigation (e.g. following other vehicles, turning and indicating). It was believed that this would help the drivers perform their driving tasks with greater efficiency.

9.4 IMPLICATIONS FOR DESIGN OF THE VIRTUAL CAR HEAD-UP DISPLAY

The virtual car head-up display concept presents aspects to consider in design. For example, the virtual car head-up display employs the collimation technique which is often used in head-up displays to tackle the misaccommodation problem. The design process of the virtual car head-up display has found this technique to be quite useful because it allows the virtual car to be presented in the driver’s field of view and appear out on the road. This can enable the navigation instructions to be tailored in the external environment and thereby can support a better understanding of what needs to be done. However, there needs to be more work done to address concerns surrounding the impact of the virtual car on the driver particularly when they drive to the car in front rather than the road as a whole. This could help to improve the design of the virtual car head-up display.

Providing navigation instructions to drivers by using the virtual car was found to be intelligible based on findings in the feasibility study. The user practices which were employed by the virtual car were understood by the drivers and they were able to follow these instructions with relative ease. Furthermore, it is possible that the design concept employed by the virtual car head-up display can contribute towards addressing some of the concerns which relate to the risk of distraction. For example, rather than process complex voice commands used to provide navigation instructions, the virtual car supports natural driving behavior by using the indicating and vehicle turning at the exact turn locations. This would only require the driver to look at the direction which the virtual car indicates and replicate the turn action on the road. This can lead to a reduction in the interference of the virtual car head-up display on the accomplishment of the primary tasks of driving. Also, it can help to enhance spatial orientation because the drivers would be shown the relative direction of the navigation instruction rather than have to work it out themselves. This enhanced spatial orientation can lead to reduced navigation errors and increase efficiency during journeys.

The virtual car head-up display reduces the complexity of the information to the driver so that the driver only sees the virtual car and follows it instead of different information on the windshield which can increase the risk of distraction. This was considered to be beneficial for reducing workload because the literature suggests that increasing the amount and complexity of information in the driver’s field of view can increase the risk of distraction. Hence, the virtual car head-up display has positive safety implications for the performance of the driving tasks because the virtual car design is simple but effective in providing the required information which are necessary for the driver to find his/her way around different environments.

The findings from the empirical work which compared the virtual car head-up display prototype with prototypes of existing navigation system found that the virtual car head-up display was associated with less workload demands and distraction when compared prototypes of existing navigation systems. It was suggested that this may have implications for the willingness of drivers to accept and use the virtual car head-up display because it is easy to learn and understand based on how real world vehicles behave. There were several application areas which were outlined for the virtual car head-up display e.g. training new drivers where they can complement instructions from driving instructors with the visual actions from the virtual car. The drivers would be shown what to do and where to go by the virtual car along the route.

From a technical point of view, there may be challenges in effectively implementing the scene augmentation of the virtual car in the desired manner to reduce interpretation problems with the instructions. For example, the driver needs to be aware that the virtual car is not another car on the road and can therefore adapt their behavior accordingly. The virtual car would need to align with the external road markings to tailor the navigation instructions effectively to the drivers. This would mean that a means of monitoring the position of the driver's vehicle in the lane would be required in order to present the required instructions accurately.

9.5 RESEARCH LIMITATIONS

The laboratory simulator environment provided a test environment which was safe and allowed the research work to be conducted. However, the effects of the driving simulator on the task may have affected drivers from displaying true behaviors because of the simulator fidelity. This can have an effect on the validity of the results from the research. The visualization of the virtual car which appeared on the virtual road may have also affected the behaviors of the drivers. There were instances where this was observed in the simulator studies where drivers left gaps for the virtual car as though it was another car driving in front of them. The limitation in the simulator setup also afforded the drivers only a limited view of the forward road which would have affected their ability to detect events at the sides of the road.

Also, there was no direct assessment of visual workload in the research with the navigation systems. Instead indirect measures were used such as glancing, peripheral detection, lane deviations and reaction times to events which occur. The assumption is that perhaps these may not be enough to indicate the extent of distraction associated with each of the navigation systems. As a result, more work may be needed to sufficiently indicate the extent of distraction with the navigation systems.

Also, the impact of the driver attributes on the use of the navigation systems was not examined which meant that individual differences in driver attributes are yet to be accounted for in the design process. Finally, the design of the virtual car head-up display was designed to suit the design of the environment in the simulator e.g. making turns, going straight and often making a few bends along the way. It was suggested that given the limitations of the virtual car used for initial testing to suit the complexity of the real world, improvements would need to be made to account for the real world contexts. In essence, the virtual car design would need to be improved upon to cater for more driving contexts than those used in this research in order to ensure that it can adapt in the real world.

9.6 DESIGN RECOMMENDATIONS FOR THE VIRTUAL CAR HEAD-UP DISPLAY IN FUTURE WORK

The virtual car head-up display has been described in this thesis as one which is aimed towards addressing the issues of additional workload and distraction in the driving task for drivers. This section provides a summary of all that has been learned concerning the design and evaluation of the virtual car head-up display so that future developers who have interest in taking the design further would have a list of design recommendations to work with. The list of design recommendations for the virtual car head-up display is as follows:

- The virtual car was configured in the driving simulator to fit within the field of view so that the instructions are visible to the driver e.g. displaying the virtual car in the driver’s line of sight and fitting it within the lane. This should be the case in future work e.g. simulator-based or real world studies to enable ease of use and understanding of the navigation instructions. It should be possible to adjust the position of the virtual car through the projection device so that drivers can optimize positioning. This would be due to the different anthropometric characteristics of the drivers.

- The indicating light should be enlarged so that it is visible to the driver. The indicating light from the virtual car once turned on should remain on until the driver makes the turn. This could help to reduce any form of confusion associated with making the turn. Also, the indicating sound should be audible so that the driver can tell when a turn to be made is being approached. The sound should be adjustable so that drivers can adjust it under varying noise levels.
- The size of the virtual car head-up display should be configured in such a way that the virtual car is large enough for the driver to easily see the visual actions displayed. However, it is important that the size should not be too large that it obstructs the driver’s view of other objects in the field of view. An acceptable size should be chosen in a real vehicle based on how it fits in the driver’s field of view.
- The turn instruction requires the same instruction set as the lane change instruction (i.e. indicating and turning). Therefore, to easily distinguish when a lane change instruction is provided from a turn instruction, the virtual car should only turn to a maximum angle of 45 degrees for the lane change but can reach 90 degrees when it is a turn instruction which is provided.

- The conformal symbology is suitable for the virtual car in the head-up display. This is because it allows the virtual car to appear situated at appropriate locations within the driving environment and tailors the navigation instructions more appropriately for the driver in the field of view when compared to a non-conformal symbology. Therefore, it would be useful if this conformal symbology is used in future work with the virtual car head-up display.
- The prototype of the virtual car head-up display has been associated with less workload and distraction of the driver's attention from the road when compared with prototypes of existing navigation systems. This means that the virtual car head-up display if fully developed can be a good alternative navigation interface to the existing navigation systems which drivers would have at their disposal for obtaining the navigation instructions they require whilst driving. Also, if there is any addition to the virtual car in future work, the eventual design should be compared against prototypes of existing navigation systems to ascertain the impacts on the performance of the driving tasks.
- Given the predominantly visual nature of the virtual car head-up display, it is important that there is less focus on attending to the virtual car and more focus on executing the primary tasks of driving. This could help to reduce any form of visual tunnelling which could arise when using the virtual car head-up display. The inactive state of the virtual car has been provided to cater for this issue but it could be useful to explore ways of improving this in future work.

- It is important that any future additions to the virtual car head-up display design concept align with the primary task of driving so that drivers can easily understand what is being provided within a short period of time. This can reduce the safety impacts which the use of the virtual car can have on the execution of the primary driving tasks.

9.7 FUTURE WORK

It would be useful to find out how the virtual car head-up display can be used in a real world navigation context and the part which context e.g. traffic, illumination, road conditions etc. would play in shaping the interactions between drivers and the virtual car head-up display. Characteristics of drivers which were not accounted for in this research can be factored in to future work with the virtual car head-up display in order to understand how differences in driver attributes can contribute to varying behavior and performances.

It is possible that personalization of the virtual car head-up display can affect its use and therefore it would be useful to identify how this can happen. Furthermore, it would be useful to assess the visual demands of the virtual car head-up display given that it involves more visual aspects than cognitive. Measures such as eye-tracking can be used to assess the visual demand which is associated with the virtual car head-up display so that if there is a way to reduce the visual demand which is associated with the navigation interface then it can be done.

9.8 SUMMARY

This chapter provided a summary of the research work. There was a statement of the research problem as per increase in workload and risk of distraction. This research therefore embarked upon the design and evaluation of a new virtual car head-up display which would be associated with less workload and risk of distraction when compared with existing navigation systems. It was found in the research that the virtual car head-up display concept is intelligible and drivers can follow the instructions which the virtual car issues during navigation. It was also found that conforming the virtual car to the road scene is better for the virtual car head-up display in order to avoid issues such as misaccommodation and attention capture. In comparison with the existing navigation systems prototypes, the virtual car head-up display was associated with the least amount of workload and risk of distraction whilst also being rated as the easiest to use.

Finally, there were several implications for design concerning the virtual car head-up display. For example, the mechanisms used by the virtual car to instruct the driver ensure that the navigation instructions are aligned to the primary driving tasks. This can have safety implications for drivers because they would spend less time and attention on translating the instructions from the virtual car and more time on executing the primary driving tasks. The virtual car can be used not just as a navigation tool but also as a training tool for new drivers where they can easily learn how to safely perform several turn maneuvers. As a result, it would be useful to commence future work soon to make the virtual car available to the public domain. The issue of acceptance of this type of new technology was discussed and the suggestion is that it could be accepted by drivers because it fits with the way the primary driving tasks are performed in the real world, thereby, allowing drivers to draw upon their competence when performing the task. It is anticipated that the virtual car would be a good addition to the range of navigation systems which vehicles drivers would have at their disposal to provide navigation instructions.

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APPENDICES

APPENDIX A

QUESTIONNAIRE FOR THE CONFORMITY EXPERIMENT

Part A: Task evaluation

Please provide a rating on the following areas (Circle the number)

1. Physical demand: How physically demanding did you find the tasks in the scenario?
   5 – Very demanding
   4 – Demanding
   3 – Can't say
   2 – Not so demanding
   1 – Not demanding at all

2. Mental demand: How mentally demanding did you find the tasks in the scenario?
   5 – Very demanding
   4 – Demanding
   3 – Can't say
   2 – Not so demanding
   1 – Not demanding at all

3. Effort: How much effort did you find you put in to accomplish the tasks in the scenario?
   5 – Too much
   4 – A considerable amount
   3 – Intermediate
   2 – Not a lot
   1 – None at all

4. Performance: Rate your performance in accomplishing the tasks in the scenario?
   5 – Excellent
   4 – Good
   3 – Fair
   2 – Poor
   1 – Fail
5. Temporal demand: How demanding did you find the pace of the tasks in the scenario?

   5 – Very demanding
   4 – Demanding
   3 – Can't say
   2 – Not so demanding
   1 – Not demanding at all

6. Frustration: What was the level of stress or irritation you faced whilst carrying out the task?

   5 – Very frustrating
   4 – Frustrating
   3 – Can't say
   2 – Not so frustrating
   1 – No frustration at all

Part B: Design evaluation

Please kindly answer the following questions. Circle or tick as appropriate

1. Did you find the events that took place in this scenario the types that you would normally face in the real world while driving? Yes / No

2. From your interaction with the virtual car head-up display, do you think that this will be a good way to display navigation information to drivers while driving? Yes / No

3. Which of the two ways in which the virtual car image was displayed did you prefer?
    a. On the real road? ☐
    b. On its own road? ☐

4. In summary, provide any general comments/recommendations you feel can be an improvement in the design of the virtual car head-up display.
....
....
....

Part C: Participant information

1. Age: .... years
2. Gender: ....
3. Number of years of driving: ....
4. Number of days per week you drive: ....

Participant ID: ....

Date: ....

Signature: ....

APPENDIX B

QUESTIONNAIRE FOR THE COMPARATIVE EXPERIMENT

Part A: Task accomplishment evaluation

Please provide a rating on the following areas for the task you carried out in the scenario.

1. Physical demand: How physically demanding did you find the task? (Circle the number)

   5 – Very demanding
   4 – Demanding
   3 – Intermediately demanding
   2 – Not so demanding
   1 – Not demanding at all

2. Mental demand: How mentally demanding did you find the task? (Circle the number)

   5 – Very demanding
   4 – Demanding
   3 – Intermediately demanding
   2 – Not so demanding
   1 – Not demanding at all

3. Temporal demand: How demanding did you find the pace of the task? (Circle the number)

   5 – Very demanding
   4 – Demanding
   3 – Intermediately demanding
   2 – Not so demanding
   1 – Not demanding at all

4. Effort: How much effort did you put in to accomplish the task? (Circle the number)

    5 – Too much
    4 – A considerable amount
    3 – Intermediate
    2 – Not a lot
    1 – None at all

5. Performance: Rate your performance in accomplishing the task? (Circle the number)

    5 – Excellent
    4 – Good
    3 – Fair
    2 – Poor
    1 – Fail

6. Frustration: What was the level of irritation, stress or discouragement you encountered while carrying out the task? (Circle the number)

    5 – Very frustrating
    4 – Frustrating
    3 – Intermediate
    2 – Not so frustrating
    1 – No frustration at all

Part B: Interface design evaluation

Please answer the following questions.

7. Did you find the events that took place in this scenario the types that you would normally face in the real world while driving? Yes / No (Circle the answer)

8. How distracting did you find using the virtual car head-up display? Circle the number.

5 – Very distracting
4 – Distracting
3 – Can’t say
2 – A little distracting
1 – Not distracting at all

9. How easy was it to navigate with the virtual car head-up display? Circle the number.

5 – Very easy
4 – Easy
3 – Can’t say
2 – A bit difficult
1 – Very difficult

10. How distracting did you find using the arrow head-up display? Circle the number.

5 – Very distracting
4 – Distracting
3 – Can’t say
2 – A little distracting
1 – Not distracting at all

11. How easy was it to navigate with the arrow head-up display? Circle the number.

5 – Very easy
4 – Easy
3 – Can’t say
2 – A bit difficult
1 – Very difficult

12. How distracting did you find using the vehicle satellite navigation device? Circle the number.

5 – Very distracting
4 – Distracting
3 – Can’t say
2 – A little distracting
1 – Not distracting at all

13. How easy was it to navigate with the vehicle satellite navigation device? Circle the number.

5 – Very easy
4 – Easy
3 – Can’t say
2 – A bit difficult
1 – Very difficult

14. Which of the three navigation interfaces did you prefer using the most? (Tick appropriate box)

a. Virtual car head-up display ☐
b. Arrow head-up display ☐
c. Vehicle satellite navigation device ☐

Part C: Participant information

5. Age: .... years
6. Gender: ....
7. Number of years of driving: ....
8. Number of days per week you drive: ....

Participant ID: ....

Date: ....

Signature: ....

Appendix C

Field study transcript

John and Allen are heading off to Nottingham football club stadium. John drives ahead of Allen to the stadium. (Allen wanted to be anonymous so there was no video recording on him). The sequence of activities which take place in the study are described as follows:

Outward journey

0:00: John turns left into new road and accelerates.

0:01: Allen drives behind John and turns left into new road. Accelerates behind John.

0:10: John turns on his indicator, slows down and stops at cross junction while waiting to spot gap in oncoming traffic going to the left.

0:12: Allen sees John indicate, slow down and stop at the junction. He turns on his indicator, slows down and stops behind John.

0:23: John spots a gap in traffic and enters it turning left into the new road.

0:26: Allen arrives at junction but stops due to oncoming traffic. He watches oncoming traffic to spot gap in traffic.

0:29: Allen spots a gap in traffic and turns left into the new road.

0:35: Allen accelerates and drives behind John. Both drivers keep driving straight.

0:55: A bus ahead in the lane stops at a bus stop. Both drivers slow down and drive past the bus.

1:02: Both drivers build up speed and keep driving.

1:53: John slows down on approaching a cross junction with a red traffic light. His brake light goes on which alerts Allen to slow down as well.

1:55: Allen sees John’s brake light go on at the red traffic light and slows down as well.

1:58: John stops on reaching the red traffic light on the left hand lane besides another car.

2:00: Allen stops in the same lane behind John.

2:02: Both drivers wait at the junction. Allen watches the traffic light and anticipates when it would turn green to resume the journey.

2:08: The traffic light turns green and the drivers resume driving.

2:13: Both drivers are in a bus lane and want to change to the vehicle lane. Other vehicles are on the vehicle lane so they try to spot gaps in the traffic to switch lanes.

2:24: John turns on his indicator which signaled to the right to make his intention of switching lanes to the right hand lane of the road known.

2:25: Allen sees John indicating to the right and also turns on his indicator to the right.

2:28: John spots a gap in the traffic on the vehicle lane and enters the gap in between the vehicles.

2:30: Allen looks into his right side mirror, spots a gap in traffic and switches lane as well.

2:32: The vehicle in between John and Allen indicates and enters the left hand lane of the road.

2:38: John stays in the right hand lane of a three lane road. Allen keeps on driving behind John and stays in the right hand lane of the road.

2:41: John approaches a junction at a roundabout and slows down.

2:42: Allen sees John's vehicle slow down as they approach the roundabout. Allen slows down as well.

2:44: John spots a gap in oncoming traffic at the roundabout and accelerates.

2:46: Allen stops at the roundabout as there is oncoming traffic approaching on the right. He waits and watches the traffic to spot a gap.

2:50: After a vehicle drives by, Allen spots a gap and accelerates. He stays in the lane and catches up with John at a set of traffic lights ahead.

3:00: John turns on his indicator signaling to the right at another roundabout.

3:09: John enters the middle lane of a three lane road and accelerates. It is the ring road heading south.

3:11: Allen sees John enter the middle lane of the ring road south and follows John into the lane. He accelerates afterwards.

3:23: Both drivers keep driving along but a traffic light is flashing amber and John slows down because there is a car waiting at the traffic light.

3:25: Allen also slows down but immediately begins to accelerate as John accelerates ahead.

3:36: John indicates to the left as he attempts to switch lanes. He enters the left lane of the road.

3:38: Allen turns on his indicator, looks into his left side mirror and enters the left lane of the road. He keeps on accelerating behind John.

4:23: John stays in the lane going straight as a vehicle ahead of him enters a side road.

4:26: Allen sees John stay in the lane and keeps following him. Both drivers keep driving along.

4:54: John slows down as vehicles ahead from a slip road on the left slow down ahead of him.

4:56: Allen sees John slowing down as the gap in between both vehicles gets smaller and he slows down behind John.

5:11: John stays in the lane going over the bridge as other vehicles exit the lane via a slip road to the left.

5:14: Allen turns on his windshield wiper as the rain gently starts to fall.

5:18: Vehicle on the right hand lane of the road drive past Allen and John as there is traffic slowly building ahead in the left hand lane of the road.

5:35: A vehicle enters the road from a slip road on the left.

5:38: John and Allen are in the middle lane of a three lane road and John turns on his indicator signaling to the left in order to switch lanes.

5:43: Allen sees John turn on his indicator and enter the left hand lane of the road. He turns on his indicator, looks into his left side mirror and enters the left hand lane of the road.

5:50: John and Allen keep accelerating along the road.

6:02: A vehicle from the right hand lane of the road enters the gap in between John and Allen.

6:05: Allen cannot see John but tries to maintain the gap between his vehicle and the unknown vehicle to avoid further increasing the gap between him and John.

6:31: John leaves the main road via a slip road on the left.

6:33: Allen sees John’s vehicle enter the slip road and enters the slip road as well. There is still the vehicle in between John and Allen.

6:42: John slows down on approaching a roundabout to turn left. His brake light goes on as he slows down.

6:45: Allen sees John slowing down along the bend leading to the roundabout and slows down behind the vehicle in between both of them.

6:50: John drives off after spotting a gap in oncoming traffic at the roundabout.

6:51: Allen slows down behind the vehicle in front and stops as there is oncoming traffic at the roundabout.

6:56: An oncoming vehicle at the roundabout drives past and enters the road where Allen should be turning into. Allen spots a gap in the traffic which he enters and accelerates. He turns left and keeps driving behind the vehicle in front of him.

7:13: The vehicle ahead enters the lane going left and Allen looks forward to see that John stayed in the right hand lane of the road at a Y-junction. He stays in the lane that John followed. Meanwhile another vehicle is between John and Allen.

7:22: A traffic light ahead turns red and John slows down and stops at the traffic light.

7:23: Allen sees John slow down and stop at the red traffic light. He also slows down and stops behind the vehicle between him and John. Vehicles from the left side road at the cross junction where the traffic light is situated begin to move. Allen and John wait at the traffic light.

7:35: The traffic light turns green and the vehicles resume driving.

7:46: The vehicles keep accelerating.

8:02: The vehicle in between John and Allen switches lanes and enters a gap in traffic in the right hand lane of the road.

8:04: Allen accelerates and catches up with John at a set of traffic lights. He keeps driving behind John.

8:42: John turns on his indicator and switches to the right hand lane of the road as the traffic light turns to amber. John drives past the traffic light and it turns red.

8:45: Allen sees the traffic light turn red and he slows down and stops. Other vehicles from the left and right side of the road begin moving. Allen waits and watches the traffic light to turn green.

9:10: The traffic light turns green and Allen resumes driving.

9:16: Allen spots John’s vehicle which pulled to the side of the road to wait for him. John’s vehicle then enters back into the road as Allen approached.

9:21: John switches and enters the right hand lane of the road and keeps driving past vehicles on the left hand lane of the road.

9:22: Allen follows John and enters the right hand lane as well.

9:50: John and Allen keep driving along.

10:35: John slows down and stops on the right hand lane of the road as traffic builds up ahead at a red traffic light.

10:36: Allen slows down and stops behind John.

10:53: The traffic light turns green and John resumes driving. Allen resumes driving as well and keeps following John.

11:00: John turns right at a junction and keep driving along.

11:01: Allen sees John turn right and turns right at the junction also. He accelerates and keeps following John.

11:36: John slows down on approaching a red traffic light and eventually stops.

11:38: Allen sees the brake light of John's vehicle come on and slows down behind John eventually stopping.

11:45: Both drivers wait and anticipate when the traffic light would turn green.

11:50: The traffic light turns green and John resumes driving. Allen resumes driving as well.

12:21: A vehicle on the left hand lane of the road indicates to the right and enters the gap in between John and Allen as the lane ahead on the left is closed.

12:46: The driver in between John and Allen switches to the left had lane of the road and keeps driving.

12:52: John slows down on approaching a set of red traffic lights at a junction leading to the A60.

12:54: Allen sees the brake light of John’s vehicle go on and slows down behind John.

12:57: John stops at the set of red traffic lights.

12:58: Allen stops behind John at the set of red traffic lights. Vehicles on the left and right side of the cross junction begin moving. John and Allen wait for the traffic light to turn green.

13:23: The traffic light turns green and John accelerates as he resumes driving. Allen resumes driving and accelerates behind John.

13:28: John turns right at the junction and keeps driving along.

13:30: Allen follows John and turns right at the junction. He accelerates and keeps driving along.

13:45: John stays in the middle lane of the road as a bus lane is on the left hand side of the road.

13:51: John slows down on approaching a red traffic light.

13:52: Allen sees John's vehicle brake light go on and slows down behind him at the red traffic light. A vehicle stops beside John on the right hand lane of the road. Also vehicles on the left side road of a junction begin moving and vehicles in the lane beside John turn into the left side road.

14:10: The traffic light turns green and John resumes driving.

14:11: Allen sees the traffic light turn green and resumes driving as well. Both drivers accelerate and keep driving along.

15:20: John turns on his indicating light to the left as he approaches a junction to turn left.

15:24: Allen sees John turn on his indicating light and turns on his indicating light also signaling to the left.

15:26: John leaves the main road via a slip road on the left.

15:28: Allen follows John and leaves the main road via the slip road.

15:36: John slows down and indicates to the left at a junction.

15:37: Allen sees the brake light of John’s vehicle come on as he slows down. He also slows down on approaching the junction.

15:38: John turns left at the junction and drives along.

15:40: Allen turns left at the junction behind John and drives along.

15:55: John slows down and indicates to the right at a junction.

15:56: Allen sees John indicating to the right and turns on his indicator signaling to the right.

16:00: John slows down and stops on arriving at the destination.

Inward journey

The game is over and both drivers commence the return journey back to Allen's house.

0:31: John drives off and indicates to the right on approaching a junction.

0:33: Allen sees John slowing down and turns on his indicator and slows down on approaching the junction.

0:35: John stops on arriving at the junction and waits to spot gap in oncoming traffic on both sides of the main road.

0:43: John turns right into the new road, accelerates and drives off.

0:45: Allen stops on arrival at the junction and waits to spot a gap in oncoming traffic on both sides of the main road.

0:54: Allen spots a gap and enters the gap. He accelerates and drives along.

0:57: John stops on the right hand lane of the road at a red traffic light ahead.

0:59: Allen slows down and stops behind John at the red traffic light. Both drivers wait along with other vehicles as they anticipate the light to turn green.

1:08: The traffic light turns green and John resumes driving as builds up speed and accelerates.

1:12: Allen sees John's vehicle begin moving and he also resumes driving as he builds up speed and accelerates.

1:18: John turns right at the traffic light.

1:20: Allen sees John's vehicle turn right at the traffic light and he follows John and turns right. Allen slowly turns right as a bus ahead of him turns at the junction.

1:27: Allen accelerates in order to catch up with John and eventually catches up with him. Both drivers keep driving along.

3:20: A vehicle turns on its indicator signaling to the right and enters the gap in between John and Allen's vehicles. Allen slows down as a result but accelerates as the vehicle accelerates as well.

3:35: John enters the middle lane of the road.

3:36: Allen sees John enter the middle lane of the road. He looks into his left side mirror and enters the middle lane of the road.

3:40: John approaches a roundabout and stays on the right hand lane of the road and takes the first exit at the roundabout.

3:42: Allen keeps following John behind and takes the first exit at the roundabout as well.

3:58: Both drivers keep driving along.

4:22: John slows down, turns on his indicator signaling to the left and enters the middle lane of the road as traffic builds up ahead on the right hand lane of the road.

4:23: Allen sees John's vehicle indicate and enter the middle lane of the road. He also turns on his indicating light signaling to the left, looks in his left side mirror and enters the middle lane of the road.

4:25: John and Allen are moving slowly as traffic is building up ahead on the road.

4:30: John begins to accelerate as the traffic moves faster.

4:31: Allen also begins to accelerate as the traffic moves faster.

4:44: John is positioned in the second lane of a four lane road.

5:00: Both drivers keep driving along.

5:45: John slows down and stops on arriving at a red traffic light as a pedestrian begins to cross the road.

5:50: Allen sees John’s vehicle slow down and stop at the red traffic light. He slows down and stops at the red traffic light behind John.

6:01: The traffic light turns green and John resumes driving and accelerates.

6:03: Allen sees the traffic light turn green and that John has resumed driving. He resumes driving as well.

6:33: Both drivers keep driving along.

6:50: John enters the right hand lane of the road and keeps driving.

6:52: Allen sees that John has entered the right hand lane of the road and follows John into the right hand lane of the road.

7:01: John slows down on approaching a red traffic light. He turns on his brake light and stops on arriving at the junction.

7:03: Allen sees John slow down and stop at the red traffic light. He slows down and stops behind John. Vehicles ahead in the opposite direction turn right at the junction. John and Allen wait and watch the traffic light as they anticipate when it would turn green.

7:30: The traffic light turns green and John and Allen resume driving as they build up speed and drive along.

8:00: John approaches a roundabout. He slows down but immediately enters a gap in the oncoming traffic on the right. He takes the second exit on the roundabout.

8:03: Allen arrives at the junction and stops as three vehicles approach from the right. He spots the gap in traffic after the three vehicles drive past and then resumes driving. He builds up speed, goes past the first exit, enters the left hand lane of the road, turns on his indicator signaling to the left and takes the second exit on the roundabout. He accelerates and catches up with John.

8:58: John positions his vehicle to enter the right hand lane of the road on approaching a junction. He also slows down and stops as there is a red traffic light at the junction.

9:00: Allen enters the right hand lane of the road behind John. He slows down and stops behind John at the red traffic light. Vehicles on the main road ahead are moving in both directions. A pedestrian ahead crosses the road.

9:33: The traffic light turns green and John resumes driving. He builds up speed and drives along going straight at the cross junction.

9:34: Allen sees the traffic light turn green and John has resumed driving. He builds up speed and drives along following John behind.

10:21: John slows down and turns on his indicator signaling to the left on approaching a junction. He switches to the left hand lane of the road.

10:27: John stops on arriving at the junction with the red traffic light.

10:28: Allen turns on his indicating light signaling to the left and slows down before stopping behind John on arriving at the junction. Vehicles on the main road at the cross junction are moving in either directions.

10:35: Both drivers wait and anticipate when the traffic light would turn green.

10:44: The traffic light turns green and John resumes driving. He builds up speed and turns left at the junction.

10:50: Allen sees John turn left at the junction. He also builds up speed and turns left at the junction.

11:27: John slows down on approach a junction with a red traffic light.

11:29: Allen slows down as he sees the red traffic light and John slowing down in front of him. Vehicles from the side road on the right at the junction begin moving.

11:28: John and Allen wait and watch the traffic light and anticipate when it would turn green.

11:48: The traffic light turns green and John resumes driving.

11:53: Allen sees the traffic light turn green and John resume driving. He also resumes driving, builds up speed and drives along. Both drivers keep driving along.

12:30: A vehicle on the left hand lane of the road drives past Allen and then John.

12:50: John enters the middle lane and slows down on approaching a roundabout. He stops on arriving at the roundabout to watch for gaps in oncoming traffic. He waits and enters a gap after a short time. It is getting darker and there is still very light rain.

12:55: Allen sees John slow down and stop at the roundabout. He slows down and stops also behind John. He watches for oncoming traffic on the right.

13:12: John spots a gap in the traffic and enters the gap. He stays in the middle lane of the road.

13:13: Allen follows behind and enters the gap as well. Both drivers drive along.

13:33: John slows down and indicates to the right on approaching a red traffic light. He enters the middle lane of the road.

13:34: Allen slows down as well but he enters the left hand lane of the road and stops behind another vehicle.

13:43: The traffic light turns green and John and Allen resume driving. They both exit the roundabout at the first exit but the trailer which was in front of Allen is now in between John and Allen. They are heading towards Allen's house and are not too far away. Allen knows the area well.

16:00: Both drivers keep driving along. Windshield wiper wiping the rain off the windshield as the rain slowly continues.

16:42: John stays on the right hand lane of the road at a Y-junction.

16:44: Allen stays on the right hand lane as well behind trailer. Allen keeps driving along but the trailer is blocking his view of John's vehicle.

17:08: John turns right at a junction ahead.

17:10: Allen sees that John has turned right and turns on his indicator signaling to the right. He waits and watches for oncoming traffic in the opposite direction and spots a gap in the traffic. He enters the gap and turns right at the junction. He catches up with John who was waiting for him after making the turn.

17:31: John turns his indicator on signaling to the right at a cross junction and turns right on arriving at the junction.

17:33: Allen sees John turn right and he then turns on his indicator light signaling to the right and follows John.

17:40: John slows down and turns on his indicating light to the left as he arrives back at Allen’s house. He stops in front of Allen’s house.

17:48: Allen slows down and stops behind John in front of his house and the journey ends.

Appendix D

Transcripts of interview sessions in feasibility study

Study 1 transcript

0:08: Interviewer: How did you find the use of the system?

0:10: Participant: Pretty easy. Very easy to follow. The one thing I thought was quite hard was to differentiate whether or not the car you're following is part of the real world. So I kept on stopping at red lights and making sure the car in front is like behind the line. So instead of thinking of my own car I was thinking about the car in front where it was going. So I was actually thinking maybe I was driving the car in front, if you know what I mean?

0:47: Interviewer: Hmm.

0:49: Participant: But subconsciously that is one thing I noticed.

0:51: Interviewer: Right so basically, you thought that was your car.

0:55: Participant: Yes, yes.

0:57: Interviewer: Whereas the main thing is it is just a car you are following. It is just a concept where you follow that car and it leads you on to where you are going.

1:06: Participant: Yes.

1:07: Interviewer: Anyway, that was quite useful. So what did you find good about the system.

1:15: Participant: I thought the braking was very useful because as soon as I saw the virtual car braking I knew I had to brake straight away and I was almost instantly grabbed into that. That is one thing that was very good. The indicator, when the indicator turned on that was also good. I had quite a quick response to that. I think that was quite good that if I was following a car and I knew that was going to the place that I wanted it to go, following the car that was quite easy.

1:47: Interviewer: So you could actually see whether it was left or right it was indicating.

1:51: Participant: Exactly, yes. And the sounds also helped as well because as soon as I heard the ticking of the indicator I knew what I should be doing there as well. So I instantly thought about turning right at that junction.

2:03: Interviewer: Ok, so do you find this system to be something that drivers would find useful in their cars and if you felt so would you recommend it to anybody?

2:23: Participant: Well, apart from the problem I had at the start, I think it would be quite a good addition to the head-up displays that are already available. But tackling the problem of not knowing what type of person is going to think that that is there car in front or if they are following it and it is just a virtual thing. I think that is the real problem because people would not really know whether to differentiate the real world from the virtual car. And even if you know it to be because even before I started I knew it was a virtual car I still found myself doing things like stopping before the red line, it is things like that, those subconscious things that I constantly did.

3:25: Interviewer: Ok because I did see that you were doing that a lot in the study when you were stopping at traffic lights, you would think that was the car in front and it was braking and you would give it some space.

3:37: Participant: Exactly, that I needed to give it some space but I did not because it was the virtual car. I think it is a very good thing to follow as a guideline but you have got to make sure that as a driver you are not using it any more than a guideline because if you start using it, say it shows to indicate right and there is a car in the way or something, you think it is alright to turn right but you should know that it is always right so I do not know how the system would know if there is like a car in the way.

4:12: Interviewer: So in the end it is a navigation tool but as a driver you have to bring in your driving skills because when it shows the driver to indicate to turn left that is where you should be going but it is not going to turn the car for you. You are going to have to turn the car yourself you still need to be aware that it is only just a navigation system and you have to take control.

Study 2 transcript

0:08: Interviewer: So tell me what you thought about this virtual car head-up display?

0:18: Participant: First of all, the scenarios are good mimics of reality, it is a good setup. Drivers can relate to the behaviour of the virtual car because they follow other vehicles while driving on the road and see these actions displayed by other vehicles. That is the virtual car kind of tells you which way to follow the car. When you turn left or right the car in front of you mimics the same movement.

1:07: Interviewer: Ok, did you think at any time that you were distracted by the virtual car from what was happening around in the environment?

1:17: Participant: No but it appeared a bit high.

1:23: Interviewer: Ok but the thing is not all heights of the drivers are the same so as a tall driver you might be seeing the car from there but as a smaller driver you might be seeing the car from there.

1:35: Participant: Maybe you should also choose what type of car that you are driving. Can you drive a truck or SUV or a normal car.

1:50: Interviewer: I think one thing that the design can look to implement is that for this virtual car head-up display, the height can be adjusted to suit the height of the driver. Anyway, in a very quick summary can you just go through the good aspects of this design?

2:10: Participant: Very good aspects, it is a very good concept that drivers can follow.

2:20: Interviewer: What areas do you think can be improved in this virtual car head-up display?

2:30: Participant: I quite liked to see the lights on the car when turning left or right.

2:36: Interviewer: The indicators?

2:39: Participant: Yes, the indicators, that was quite good, could do with more braking lights, for example, when to have slow down from 50 to 30 because of the bends.

2:58: Interviewer: Ok, so also do you think this virtual car is something that many other drivers would find useful and if you think so would you recommend it to other drivers to use it?

3:11: Participant: Yes, yes. For example, you can say show me the way to get from A to B and let the virtual car do it.

3:25: Interviewer: Yes, that is an interesting concept which is the follow me concept in the virtual car head-up display.

3:33: Participant: Yes.

3:35: Interviewer: You can require the virtual car to provide this information and it can show you the way.

3:45: Participant: It can just be like saying I want to take a trip from A to B, I do not know what type of traffic I would encounter today but can you just take me from A to B and I will follow behind your car.

4:00: Interviewer: Yes, that is possible and in fact that is the concept behind the virtual car. It cuts away all the imagery that vehicle navigation systems gives you and that type of interface and simply provides something that you can actually see and as a driver you can use that to lead you to your destination.

4:30: Participant: True, you might not even have a car. You might have a motor bike.

4:35: Interviewer: That can always be possible and it can be extended to other things but this is just an interface for car drivers.

Study 3 transcript

0:02: Interviewer: So after having that test with the system what did you think about the concept of this head-up display?

0:14: Participant: Well, it is definitely useful and easier to understand than the normal vehicle satellite navigation device if I am to compare it to normal devices which I am using because it does not shift your focus off the road. With the vehicle satellite navigation system, especially if you do not know where you are going then you have got to be focusing on the vehicle satellite navigation system really more than the road. But with this one your eyes are actually on the road, your eyes are never off the road. In that sense it is very useful but what I might be concerned about is if I were to be doing a long journey, say a 150 mile journey, is the display going to be there all the time especially if I know that I would be on a 50 mile stretch on a road, so maybe can I switch off the display and then put it back on when I am going off the motorway, so I am not sure how that would be.

1:29: Interviewer: Well to be honest, if you do not really need it then it can just be there but maybe minimize but if you do not really need it you know it is there but you do not need it.

1:42: Participant: Right, ok. So it would not really distract you?

1:49: Interviewer: Yes, it would not really distract you because it would just be there but not doing anything. If it knows you would not be indicating it would just be there and not do anything. So, another important thing is did you feel at any time that you were more distracted by what the virtual car was doing compared to you keeping your eyes off the road?

2:13: Participant: No, no, not at all. From the test, the setup looks very similar to an actual car but because the rear view mirror appeared at the bottom I just forget to check what is behind me but in terms of like focusing on the actual road, no, it does not take attention away from the road.

2:46: Interviewer: Ok, so it was more like you had an awareness of the environment and the car?

2:52: Participant: Absolutely, yes.

2:55: Interviewer: Because there is always this problem of people trying to zoom in their focus on something that can actually be seen on the road so if you can actually see that virtual car and you are following the car then it is more likely that your attention might be zoomed into that image that you are trying to focus on.

3:13: Participant: For me not at all because in the test there were like people crossing the road, red traffic lights and even on the motorway I was able to easily read the road signs “queue ahead” and at the same time attend to the virtual car.

3:29: Interviewer: Ok. You’ve rightly pointed out that one of the good aspects of this design is that it actually keeps your attention on the road, you can see what the virtual car is doing.

3:54: Participant: Yes, if you are going somewhere and you have to look at the directions particularly in inner city driving, it does not distract you from what is going on.

4:37: Interviewer: Ok, so basically looking at this virtual car system whilst you were driving, what sort of areas do you think the virtual car can be improved upon?

5:02: Participant: If there is also some sort of setting where there is voice control which can be added, for example, if you are driving at 40 and approaching a 30 mile zone, if there is some sort of system that can notify you of this need to change speed.

5:34: Interviewer: So the system should notify you that are driving into a zone where your current speed is higher than the speed limit?

5:37: Participant: Absolutely, yes, it should tell you that you are driving above the speed limit and maybe if you are five miles away from your next exit it can tell you because most of the current vehicle satellite navigation systems like TomTom have that voice command in them. So if this can be fitted with some sort of voice command for driving, especially city driving then that would be useful.

6:01: Interviewer: Ok.

6:02: Participant: I think so.

6:06: Interviewer: So basically do you think this system can be helpful to drivers in general and if you think so would you recommend it to someone else if it is fully developed?

6:23: Participant: I think I would buy it if it is implemented. At the moment I have not been convinced to go and buy a vehicle satellite navigation system, I just use google maps to sort out my directions from the beginning. And I am not that bad with directions but something that I am not sure about is this is whether it is something you can purchase this separately or you have to buy it with the car but if I would definitely recommend it anyway.

7:00: Interviewer: Ok.

Study 4 transcript

0:03: Interviewer: So just very briefly what do you think of the concept of this virtual car head-up display?

0:12: Participant: To the best of my knowledge, with my experience of using a vehicle satellite navigation system and this virtual car head-up display, this obviously makes me to be more focused on the road and does not really distract me which is quite interesting and based on the idea that the car can indicate when to turn or when not to turn that was good. It uses the real picture of the environment which the vehicle navigation system does not do. For example, the vehicle satellite navigation system instructs you to keep going or do something, you are the one that actually has to use your initiative to know if there is a car in front of you and stop or not whereas this virtual car has an edge over that given that it is providing the information in relation to the real world information, so it tells you to stop when you need to stop and turn when you need to turn and all that. So it is pretty much better than the vehicle satellite navigation system and it actually uses less effort to achieve the same tasks which you would achieve with vehicle satellite navigation systems.

1:30: Interviewer: Ok. There was one thing that is of interest which is when you were driving and following the virtual car did you find yourself concentrating on what the car was doing or on the field of view in front of you? Did you find you narrowed your vision away from the road because of the virtual car?

1:57: Participant: No, I focused on the car but still paid more attention to the environment itself. That was because the virtual car was an image which appeared as part of the field of view.

2:49: Interviewer: So you have said that you liked the fact that this virtual car allowed you to focus more on the road and showed you what to do by indicating, stopping and all that, I can tell that these are some of the good things that you like about this design when compared with other navigation systems but now looking generally what sort of areas do you think can be improved?

3:35: Participant: Well, before I answer that I would also like to add to those things you mentioned that the virtual car is good because it does most of the work for the driver, for example, it turns on the brake light at red traffic lights, shows you where a turn direction is, the virtual car shows you these things but with the vehicle navigation systems you have to do these things. You actually have to observe the environment and perform these actions compared to this where the virtual car sort of does things for you. This may affect the attention on the road though. So, in terms of the improvements, I think voice assistance would be quite good for this system because if you are following the car and you need to perform an urgent action e.g. brake or turn left it would inform you to take these actions and even if you miss the indication then the voice would be helpful, for me it would be highly recommended.

4:52: Interviewer: Ok. So you are saying that the audio instructions would be useful for complementing the visual display on the windshield?

4:58: Participant: Yes.

5:00: Interviewer: That is good but in the design of this virtual car it was important to reproduce the situations of the real world because you do not hear instructions from a car when following it in the real world but nevertheless, I think it is an area that might get attention later on. Just moving on then, there were times when you were driving that I realized that you may have perceived this virtual car to be another car on the road. I could see at traffic lights and certain places where when the car was stopping it appeared that you stopped behind the virtual car which was in front of the white line at the traffic light. In the simulator there may have been an issue with this but maybe in the real world this would not have been the case.

6:07: Participant: Yes.

6:10: Interviewer: Do you think that this system would be helpful to other drivers, do you have safety concerns and if you do not would you recommend it to other drivers for navigating?

6:20: Participant: Well, given that we pointed out that it is possible that drivers may think this is their car on the road not another car they are following there needs to be a way of subduing that sub consciousness of them thinking that it is actually another car on the road and to let them know that it is actually a car that is giving them directions on where they are going to which does not exist on the road because I think it may help with the whole gap problem and any other safety issue. The system would be helpful to other drivers if that is dealt with. I think with improvements the virtual car would get better and yes I would recommend it if these things are addressed.

7:50: Interviewer: Ok. I think those who would implement this in real vehicles would also look into this issue and find a solution.

Study 5 transcript

0:04: Interviewer: So what did you think about the concept of the virtual car head-up display?

0:07: Participant: I think the concept was good and I think it makes more sense when you are not sure where you are going and you need lots of directions. So I can see this as a good replacement for the normal kind of vehicle satellite navigation system and I can also see it as a good tool for helping people who are learning to drive. For example, I guess like on the motorway example, it was probably less useful just because it was a long stretch and you are not likely to be doing anything other than changing lanes. But in the urban environment example, it is more useful because there are corners to turn around and junctions with traffic lights and things like that.

0:59: Interviewer: Ok. At any time did you feel you were more distracted from the environment by what the car was doing so did you have more focus on the car than what was happening around the car.

1:11: Participant: No not all. I think the only distracting this is that in the simulator setup it is hard not to imagine yourself as driving the car in front rather than your car but I do not think that would be the same on a real road. I think that might be a problem with the simulator but in general I do not think the virtual car distracted me from the environment at all.

1:32: Interviewer: Right, I did realize that one thing that is common is that it was hard to think that you were not driving that car in front and it happened in some cases where when you got to the traffic light you actually stopped behind the car.

And the thing is if you had gone close to the white line and the virtual car had just driven past it there would not have been any problem. I can see that people may think that they are following this car and it looks real so they may orient themselves to this car.

2:19: Participant: Part of this might relate to computer games because there are lots of computer games where you are driving along and what you are driving is an image of a car in front of you.

2:27: Interviewer: Yes.

2:28: Participant: So it feels like it might be a computer game that you have played before. So maybe something that looks quite different from that may stop that from happening because now it looks like you have got a car in front of you so your brain starts to think that you have to drive it.

2:50: Interviewer: Ok. In just a few words what do you think are the good aspects of this design?

3:00: Participant: I think the kind of good aspects of this are that it is kind of not intrusive, so it does not kind of distract you from the road particularly and it can give you directions if you needed them. And I think it is less distracting being shown to you than directions being told to you. I think this is less distracting. I think voice instructions I find quite distracting when I am driving. Obviously looking at a map is very distracting as well but I think of these three things being shown the instructions is the least distracting option. I think those are the good things.

4:11: Interviewer: Ok, are there any areas that you think can be improved upon?

4:15: Participant: I think there are features that would be good to add. For example, in some sections of the road I did not know what the speed limit was and I did not want to go too fast. So if there was some way of the car could indicating to me that I was going too fast. So maybe I am driving on a motorway on a straight road and I exceed the speed limit maybe the brake lights can come on then I would know, yes, that would be good. Also at the moment it is quite a realistic car but only certain features of it are quite important, so for example, the brake lights and the indicator lights are probably the most important things, so if they were bigger so that you could see them more clearly it would not look like a real car any more but it would be more obvious to notice.

5:14: Interviewer: So if it was going to indicate left, the car's indicating light can zoom out and start indicating.

5:20: Participant: Yes, something like that.

5:21: Interviewer: And then when it turns it would just zoom back in.

5:22: Participant: Yes something like that. So it does not necessarily have to look exactly like a real car, the importance is just how clear is it to see those signals. And I think another thing might be having the ability to turn it on and off might be useful.

5:40: Interviewer: Ok.

5:41: Participant: So for example, if you are on the motorway section then you do not need it and you might completely want to have all your attention on the motorway whereas if you are on the section where you need directions then maybe you can turn it back on again. So the things is there are times when the hard job on the road is navigating and there are times when the hard job on the road is driving. So I think when you are actually driving it is better to turn it off but if you are wanting to navigate and wanting the directions that it can give you then turning it on would be good. So turning it on and off would be useful.

6:15: Interviewer: So you do find when there are journeys which have part of it as a motorway and part of it as a city, so you do need the system to be dormant at times when you do not really need to do anything. When you are on a stretch of road it may be minimized or something but the problem comes when you are entering the city, the system would have to know that you are entering the city where there would be more turns then it would actually have to come back up again.

7:05: Participant: Well, yes.

7:06: Interviewer: Ok, I see the point you are making that you might want to get it out of your field of view when it is not doing anything but it might as well not distract you if it is there and not doing anything.

7:25: Participant: Well, I think the point can be that as a driver you just have to be in control of what you are attending to. I think that it would be easier for people in the real world compared to this type of study where you are not really driving so you may not really have the same motivation as when you want to get into the car and go somewhere. So in the real world, you would likely be more in control and tell that this was just made to help you whereas in the simulator it is bit more complex to try and understand whether you are supposed to be in control or whether the virtual car is supposed to be in control. A lot of those things would disappear in the real world. I think those are the main things.

9:08: Interviewer: Do you think this system is something that users would find helpful and would you recommend it to people for navigating just like the vehicle satellite navigation systems?

9:21: Participant: Yes, I think so that it would be quite useful. I think that I would use something like that rather than a vehicle satellite navigation system.

9:35: Interviewer: Ok.