The impact of interaction mechanisms with in-vehicle touch screens on task performance

Ayse Leyla Crossland[1], Gary Burnett[1], David R Large[1], Catherine Harvey[1]

[1]Human Factors Research Group, University of Nottingham, Nottingham, UK

ABSTRACT

Although they provide a better driving experience, the developments within in-vehicle technologies also raise concern due to their contribution to driver distraction. Especially the introduction of in-vehicle touch screens has the potential to increase visual demand by the in vehicle information system (IVIS). It is crucial to conduct research to identify different ways for drivers to interact with in-vehicle displays in order to decrease the visual demand placed on the driver. The driving simulator study discussed in this paper aimed to investigate the effects of driving complexity (stationary, simple, complex) and different interaction mechanisms (foveal vision, peripheral vision, muscle memory) with in-vehicle touch screens on a secondary task, driving performance and NASA TLX scores. The results showed driving complexity had no significant effect on secondary task and driving performance. However, button selection task time and error rates were significantly higher during muscle memory conditions compared to peripheral and foveal vision conditions. Conversely, foveal and peripheral vision had a negative impact on driving performance unlike muscle memory conditions. Overall, this study highlighted the similarities between foveal and peripheral vision but also the potential to encourage drivers to keep their eyes on the road by considering peripheral vision as an interaction mechanism when designing in-vehicle touch screens.

KEYWORDS

IVIS, visual demand, peripheral vision, driver distraction

Introduction

There have been significant enhancements in in-vehicle technologies over the last decade which have introduced different types of displays such as touch screens and head-up displays (HUDs) for drivers to interact with (Becker, Hanna, & Wagner, 2014). These new types of displays enable drivers to perform a variety of secondary tasks such as browsing the internet or having access to social media that they were not able to with traditional in-vehicle displays. In-vehicle touch screens are gradually replacing physical buttons and are still growing in size (Rümelin & Butz, 2013). The way drivers interact with these displays is also changing, resulting in concerns about driver distraction due to increased visual demand placed on the driver by in-vehicle touch screens (Burnett, Summerskill, & Porter, 2004). According to NHTSA in 2016 3,450 were killed on US roads as a result of driver distraction and 9.2% of total fatalities were distraction related (NHTSA, 2017). Driving is known to be a highly visual task (Owsley, Stalvey, Wells, & Sloane, 1999). With drivers typically spending 90% of their time looking at the road ahead when driving (Burnett & Joyner, 1997). Hence it is crucial that drivers keep their eyes on the road ahead whilst driving. The aim of this study was to investigate the effects of different interaction mechanisms adopted by drivers when interacting with in-vehicle touch screens and the effects of driving complexity on secondary task performance when using the different interaction mechanisms. A previous study conducted by Eren et al. (2018), aimed to investigate the relative effects of two interaction mechanisms – peripheral vision and muscle memory – which are shown to be relevant to visual behaviour when driving on task time of a button selection task on an in-vehicle touch screen. The current study built on the results of this study to compare the performance of peripheral vision and muscle memory to foveal vision and to understand the effectiveness of the different interaction mechanisms under different levels of driving complexity.

Based on existing research in literature it was known that driving complexity can influence when and how drivers choose to interact with in-vehicle displays – the more demanding a driving environment is (e.g. harsh weather conditions, constant need to change speed, traffic, presence of other cars on the road, etc.) the less spare capacity the driver will have to allocate to the secondary task (Young & Regan, 2007). This study aimed to identify the impact of changes in primary task demand by asking participants to drive under various levels of driving complexity.

The aim of the study discussed in this paper was to investigate the effects of three interaction mechanisms (muscle memory, peripheral vision, and foveal vision) and three levels of driving complexity (stationary, simple, and complex) on in-vehicle display button selection task performance. The following three research questions were explored:

1. How does driving complexity impact task time?
2. How does interaction mechanism impact task time?
3. What is the relationship between driving complexity and interaction mechanism?

Method

Participants

Twenty participants (11 males, 9 Females) from the University of Nottingham took part in the study (mean age = 40 years; s.d = 10). All participants held a UK driving licence for at least 1 year (average time with licence = 20 years; average annual mileage = 7788 miles) and were also experienced in using touch screen devices such as smartphones and tablets.

Design

The study used a within-subjects design. There were two independent variables; driving condition (stationary, simple and complex) and interaction mechanism (muscle memory, peripheral vision and foveal vision), resulting in 9 drives. During the stationary driving condition, participants were sat in the driving simulator, but the vehicle remained stationary in the hard shoulder of a UK-style motorway scenario. The simple driving condition involved participants driving in the slow lane on a straight motorway following a lead car (Alm & Nilsson, 1995) which travelled at a constant speed of 60 mph with no other traffic on the road. The complex driving condition similarly took place on a motorway but there were some bends on the road, the lead car's speed varied between 65-75 mph and there was other traffic present on the road (Large, van Loon, Burnett, & Pournami, 2015). For all driving conditions during which participants were in control of the vehicle, participants were asked to keep a safe distance between themselves and the lead car and to always stay in the left-hand lane of the motorway. No lane changes were performed during any of the drives. Participants were also instructed to interact with the touch screen that was located within the centre console of the simulator (Figure 1) whilst driving or stationary. They were provided a single, white square button (12 x 12 cm) at a time on the touch screen and were asked to press the button as quickly and as accurately as possible. They were reminded to drive as they would in a real driving environment and that the primary task was the driving task. They heard an audible tone every time the button appeared on the screen and a different tone once they had successfully pressed the button. If they failed to locate the button on their first attempt, participants were instructed to keep trying until they heard the confirmation sound. The button was displayed on the same location on the screen within each condition. However, the location of the button differed in between conditions. So overall, the buttons appeared in 9 different locations.

Figure 1. Left: Location of the in-vehicle touch screen, Right: A participant wearing the glasses used for the muscle memory condition

There were three different interaction mechanisms participants used when pressing the button on the touch screen: muscle memory, peripheral vision, and foveal vision. During the muscle memory conditions participants were asked to wear a pair of glasses which blocked their peripheral vision, so they could not see the touch screen when interacting with it (Figure *1*). Before each muscle memory condition participants were shown where the button would appear on the screen, so they had an idea of where to place their finger on the touch screen. During the peripheral vision conditions, participants were instructed to keep their eyes on the lead car at all times and only use their peripheral vision to detect the button appearing on the screen. Finally, during the foveal vision conditions participants were asked to keep their eyes on the lead car in between button presses but to look directly at the touch screen when pressing the button. During peripheral and foveal vision conditions participants were asked to complete 24 button presses and during muscle memory conditions the number of repetitions was 50. During all conditions participants were monitored using the cameras placed in the simulator to ensure that they were following the appropriate instructions specific to each condition.

Consequently, there were 9 conditions in total and each condition was a different combination of driving condition and interaction mechanism. However, participants only experienced one interaction mechanism per condition. The order of the conditions was counterbalanced between participants. Each condition lasted for approximately 10 minutes. At the end of each condition participants were asked to complete a NASA TLX workload questionnaire (Hart & Staveland, 1988). Other dependent variables were task time and error rate. Task time was recorded from the moment the button appeared on the screen until the moment the participant pressed the button, and error rate was calculated based on the number of times the participant touched the screen but did not press the button during this time. There were also video cameras in the simulator facing the participant and the touch screen they were interacting with to capture behavioural data.

Procedure

At the beginning of the study participants were asked to complete a pre-trial consent form and data capture questionnaire followed by a post-trial consent form at the end of the study. They were asked to complete a simulator sickness checklist both at the beginning and end of the study to make sure that they were not experiencing any negative symptoms due to driving the simulator. The data capture questionnaire asked participants about their age, gender, driving license, annual mileage, and touch screen device use. Each participant was given a number on arrival to ensure their anonymity.

Once the forms were completed participants were given the opportunity to drive the simulator in the complex driving condition for 10 minutes to familiarise themselves with the controls and the driving scenario. During the study at the end of each drive they were given the opportunity to rest and were also asked to complete a NASA TLX form to capture the subjective workload for each drive. At the end of the study participants were given vouchers for their time and were advised to wait 30 minutes before driving their own car.

Results

Button Selection Task Time

A two-way repeated measures ANOVA was carried out to determine the effect of interaction mechanism and driving complexity on the button selection task time. There was no statistically significant two-way interaction between driving complexity and interaction mechanism, $F\ (2.327,44.205) = 0.829$, $p = 0.459$. However, there was a significant effect of interaction mechanism on task time, $F\ (1.126,21.385) = 50.954$, $p = 0.0005$.

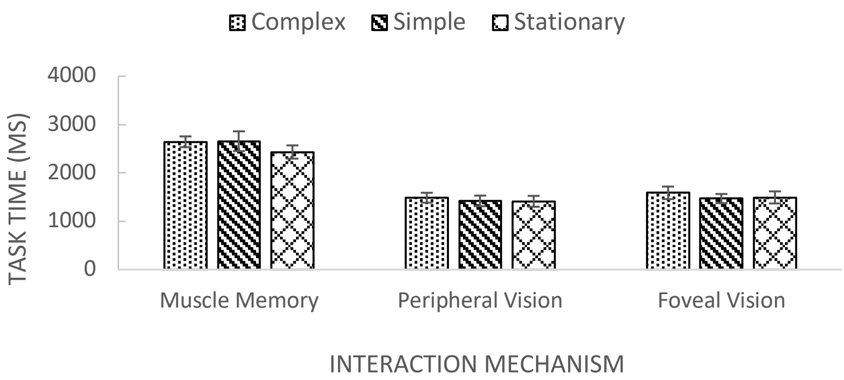

Figure 2. Average task time for all conditions across all participants (error bars: Standard Error)

As seen in Figure 2, task time was significantly higher for muscle memory conditions compared to peripheral vision conditions 1140.74±147.24 ms and foveal vision conditions 1070.1±156.33 ms. Participants took a significantly longer time to complete the task when they could not see the touch screen during all levels of driving complexity.

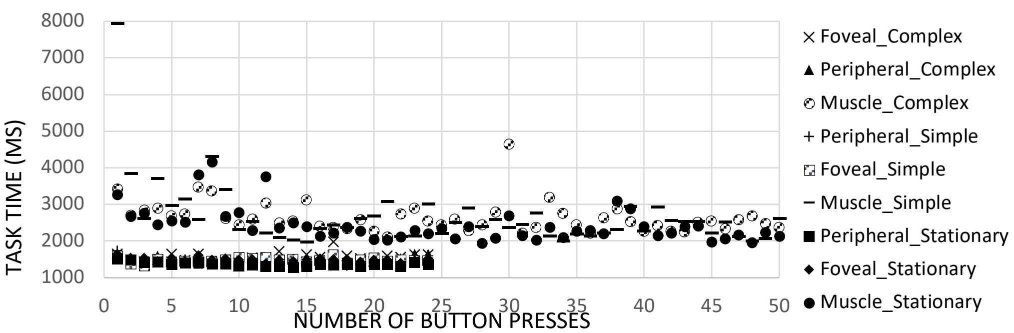

Figure 3. Task times for all interaction mechanisms across all drives

Based on observations made from the videos recorded during the study, during muscle memory conditions participants started developing a certain amount of muscle memory, however they lost this after a while to then start developing it again. These spikes can be seen in Figure 3.

Button Selection Task Error Rates

The number of attempts it took for participants to press the button correctly was recorded during the study. A two-way repeated measure ANOVA was carried out to determine the effect of interaction mechanism and driving complexity on error rate. There was no statically significant two-way interaction between driving complexity and interaction mechanism, $F (1.481, 28.139) = 0.334$, $p = 0.654$. However, the type of interaction mechanism had a significant effect on error rate, $F (1.013, 19.253) = 36.881$, $p = 0.001$. Data show that participants made more errors – did not press the button correctly the first time – during muscle memory conditions compared to peripheral and foveal vision conditions (Figure 4). There was no significant difference between the peripheral and foveal vision conditions in terms of error rates.

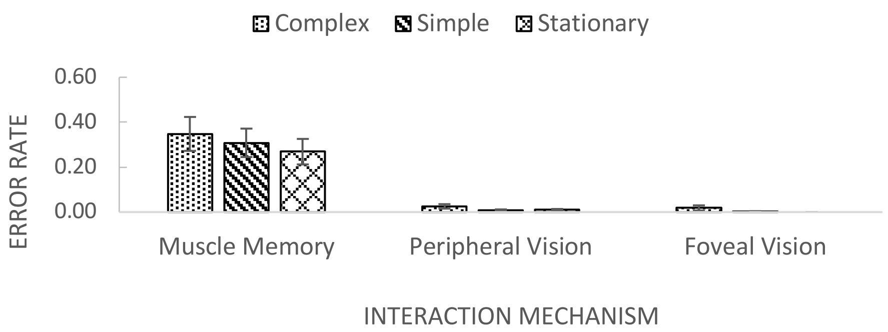

Figure 4. Average error rate for all conditions across all participants (error bars: Standard Error)

NASA-TLX

A two-way repeated measures ANOVA was run to determine the effect of interaction mechanism and driving complexity on overall NASA TLX scores (Figure 5).

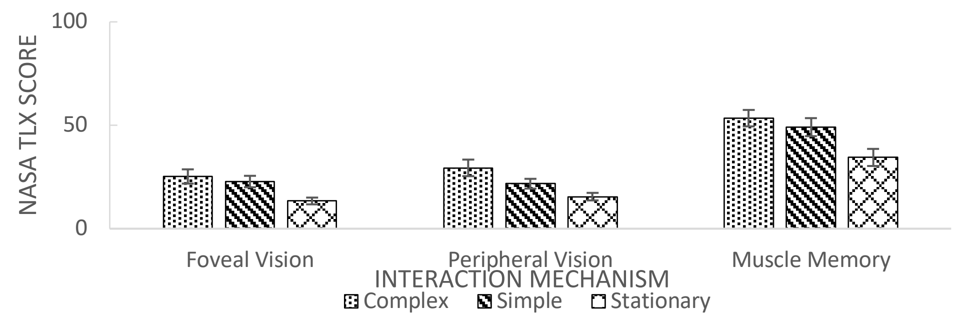

Figure 5. Overall NASA TLX results (error bars: Standard Error)

There was no statistically significant two-way interaction between interaction mechanism and driving condition $F (2.729, 51.854) = 1.713$, $p = .180$. However, there was a statistically main effect of interaction mechanism, $F (2, 38) = 30.504$, $p = .0005$ and driving condition, $F (1.291, 24.536) = 59.623$, $p = .0005$ independent of each other.

Driving Performance

A two-way repeated measures ANOVA was run to determine the effect of interaction mechanism and driving complexity on the standard deviation of lane position and standard deviation of speed (Figure 6). There was no statistically significant two-way interaction between interaction mechanism and driving complexity on the standard deviation of lane position, F (2, 34) = .885, p = .422. However, the main effect of interaction mechanism showed a statistically significant difference in lane position F (2, 34) = 40.922, p = .0001. Muscle memory as an interaction mechanism had significantly less effect on lane position than peripheral vision and foveal vision. Standard deviation of lane position increased by 0.835 ft (p = 0.0001) and 0.733 (p = 0.0001) ft during foveal vision and peripheral vision conditions respectively.

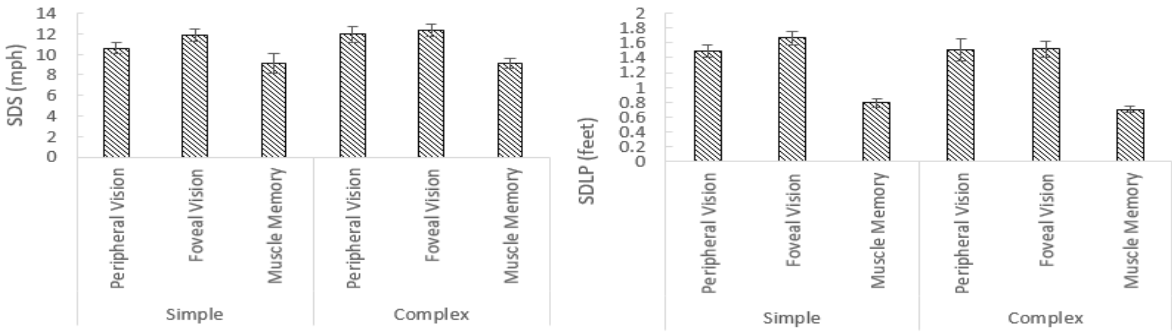

Figure 6. Standard deviation of lane position (error bars: Standard Error)

There was no statistically significant two-way interaction between interaction mechanism and driving complexity, F (2, 34) = .486, p = .619. The main effect of interaction mechanism showed a statistically significant difference in change in speed F (2, 34) = 12.963, p = .0001. Muscle memory as an interaction mechanism had significantly less effect on speed than peripheral vision and foveal vision. Standard deviation of speed increased by 2.854 mph (p = 0.0001) and 2.022 mph (p = 0.020) ft during foveal vision and peripheral vision conditions respectively.

Discussion

This study aimed to understand the impact of the combination of the interaction mechanism used to interact with the in-vehicle display and driving complexity on mainly secondary task and also driving performance and subjective workload. The independent variables were driving condition (stationary, simple and complex) and interaction mechanism (muscle memory, peripheral vision and foveal vision). Objective and subjective data was collected in the form of task time, error rate, driving performance and NASA TLX scores. The role of both peripheral vision (Summala, Nieminen, & Punto, 1996) and muscle memory (Charlton & Starkey, 2011) has been investigated previously in the context of driving as a part of the primary task of driving. However previous work has not considered these two interaction mechanisms in relation to the interaction with in-vehicle displays whilst driving. This study also aimed to address this gap in literature by providing a better understanding of the role of peripheral vision and muscle memory as a part of the secondary task interaction (Eren, Burnett, Large & Harvey, 2018).

The data collected showed similar results for peripheral and foveal vision interaction in terms of their impact on the button selection task performance and driving performance. When participants were asked to rely on muscle memory when interacting with the in-vehicle touch screen they took significantly longer to complete the button selection task and ended up making more errors when completing the task. Consequently, the more errors made the higher task time was. Peaks were observed in the muscle memory button selection task time data at certain points. These peaks may have occurred for a number of reasons such as fatigue or a result of enforced repetition of the same task in rapid succession.

Adversely both peripheral and foveal vision as an interaction mechanism had a significantly worse impact on driving performance than muscle memory. This was expected for foveal vision as participants were specifically instructed to take their eyes off the road when performing the button selection task. As shown in other studies in literature the more drivers take their eyes off the road the worse their driving performance becomes (Engström, Johansson, & Östlund, 2005; Horberry, Anderson, Regan, Triggs, & Brown, 2006). As for peripheral vision, participants were still using a part of their vision when interacting with the touch screen that aid drivers in lane keeping and headway detection when driving (Lamble, Kauranen, Laakso, & Summala, 1999; Summala, et al., 1996). As a result, it was not surprising that the use of peripheral vision as an interacting mechanism had a degrading impact on certain aspects of driving performance unlike muscle memory.

NASA TLX results show that participants' subjective ratings of their performance were significantly worse for muscle memory conditions, which is supported by the task time data. This implied that participants found interacting with the touch screen less frustrating and demanding during stationary conditions. This was also expected as during stationary conditions they were only performing one task unlike the simple and complex driving conditions during which they were having to split their attention between the driving and button selection task.

The similar results for peripheral and foveal vision in terms of button selection task time, error rates and driving performance highlighted the similarities between the two different types of interaction mechanisms. This also emphasised the potential to use peripheral vision when interacting with in-vehicle touch screens in order to encourage drivers to keep their eyes on the road. Although a single button was presented on the touch screen at a time during this study, it is recognised that in a real driving environment, drivers would be more likely to interact with displays that present multiple targets to choose from whilst driving. It is believed that there are specific stages of a target selection task on an in-vehicle touch screen that can benefit from the use of peripheral vision such as the ballistic, homing and selection stages of the aiming movement (Biswas & Langdon, 2012). Future work will focus on identifying different aspects of touch screen design that aid peripheral vision interaction for some of these aspects of the target selection task.

References

Alm, H., & Nilsson, L. (1995). The effects of a mobile telephone task on driver behaviour in a car following situation. *Accident Analysis and Prevention*, *27*(5), 707–715.

Becker, S., Hanna, P., & Wagner, V. (2014). Human Machine Interface Design in Modern Vehicles. *Encyclopedia of Automotive Engineering*.

Biswas, P., & Langdon, P. (2012). Developing Multimodal Adaptation Algorithm for Mobility Impaired Users by Evaluating Their Hand Strength. International Journal of Human-Computer Interaction, 28(9), 576–596. https://doi.org/10.1080/10447318.2011.636294

Burnett, G., & Joyner, S. M. (1997). An assessment of moving map and symbol-based route guidance systems. *Ergonomics and Safety of Intelligent Driver Interfaces*, 115–137.

Burnett, G., Summerskill, S., & Porter, J. M. (2004). On-the-move destination entry for vehicle navigation systems: Unsafe by any means? *Behaviour & Information Technology*, *23*(4), 265–272. https://doi.org/10.1080/01449290410001669950

Charlton, S. G., & Starkey, N. J. (2011). Driving without awareness: The effects of practice and automaticity on attention and driving, 14(6), 456–471. Retrieved from https://www.sciencedirect.com/science/article/pii/S1369847811000490

Engström, J., Johansson, E., & Östlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *8*(2 SPEC. ISS.), 97–120. https://doi.org/10.1016/j.trf.2005.04.012

Eren, A. L., Burnett, G., Large, D. R., & Harvey, C. (2018). Understanding the effects of peripheral vision and muscle memory on in-vehicle touchscreen interactions. *IET Intelligent Transport Systems*. Retrieved from http://eprints.nottingham.ac.uk/50499/1/Eren-Peripheral vision-IET-ITS.pdf

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in Psychology*, *52*, 139–183.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention*, *38*(1), 185–191. https://doi.org/10.1016/j.aap.2005.09.007

Lamble, D., Kauranen, T., Laakso, M., & Summala, H. (1999). *Cognitive load and detection thresholds in car following situations: safety implications for using mobile (cellular) telephones while driving*. *Accident Analysis and Prevention* (Vol. 31). Retrieved from www.elsevier.com/locate/aap

Large, D. R., van Loon, E., Burnett, G., & Pournami, S. (2015). Applying NHTSA task acceptance criteria to different simulated driving scenarios. *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '15*, 117–124. https://doi.org/10.1145/2799250.2799254

NHTSA. (2017). 2016 Fatal Motor Vehicle Crashes: Overview. *Traffic Safety Facts: Research Note (DOT HS 812456)*, (October), 1–9. https://doi.org/DOT HS 812 456

Owsley, C., Stalvey, B., Wells, J., & Sloane, M. E. (1999). Older Drivers and Cataract: Driving Habits and Crash Risk. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *54*(4), M203–M211. https://doi.org/10.1093/gerona/54.4.M203

Rümelin, S., & Butz, A. (2013). How to make large touch screens usable while driving. *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '13*, 48–55. https://doi.org/10.1145/2516540.2516557

Summala, H., Nieminen, T., & Punto, M. (1996). Maintaining lane position with peripheral vision during in-vehicle tasks. *Human Factors*, *38*(3), 442–451.

Young, K., & Regan, M. (2007). Driver distraction : A review of the literature. In I. J. Faulks, M. Regan, M. Stevenson, J. Brown, A. Porter, & J. D. Irwin (Eds.), *Distracted Driving* (pp. 379–405). Syndey. https://doi.org/10.1201/9781420007497