Exploring two interaction mechanisms for in-vehicle touch screens: Peripheral Vision and Muscle Memory

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Abstract: There is a need to understand how in-vehicle touchscreens can be designed to minimise "eyes off road" time. We investigated the relative effects of two mechanisms shown to be relevant to visual behaviour when driving, but previously not considered together in the context of in-vehicle touchscreen use: peripheral vision (PV) and muscle memory (MM), i.e. motor learning. This study was designed to isolate and observe the effects of PV and MM on the time to press different sized buttons (small 6x6cm, medium 10x10cm, large 14x14cm) on an in-vehicle touchscreen. Twenty-five participants were seated in a driving simulator and were presented with a single, white, square button on the touchscreen on 24 successive occasions. For MM conditions, participants wore a pair of glasses that blocked their peripheral vision and for PV conditions they were asked to focus on the vehicle in front. Results show that task time was significantly higher during MM tasks at the beginning of each condition compared to task time for PV tasks. NASA TLX results showed that perceived workload was significantly higher during MM in comparison with PV conditions. Results suggest that for interfaces that utilise peripheral visual processing the learning effect is not evident and operation times are constant over time. This suggests that in-vehicle touch screens can be designed to utilise peripheral vision for making simple button selections.

1. Introduction

The latest technological developments provide high functionality in In-Vehicle Information Systems (IVIS). Drivers can now perform complex tasks using in-vehicle touch screens that they were not able to do with traditional manual displays. The increase in the complexity of these tasks also results in more visual attention required from the driver towards the inside of the vehicle at the expense of the outside driving environment. Drivers taking their eyes off the road frequently and for longer periods lead to distraction, which can result in accidents [22].

The aim of this study was to investigate the extent to which different human performance processes (visual and manual) can be used to support 'non-visual' operation of an in-vehicle interface. There are two interpretations of 'non-visual' operation which are relevant in driving. Completely 'non-visual' operation would involve drivers selecting options on a display screen completely 'blind', i.e. without using any vision, only motor movements (or 'muscle memory') to the screen. We may also seek to achieve a partial 'non-visual' state, in which drivers can attend to an in-vehicle touch screen using peripheral vision, whilst attending to the road and primary driving tasks such as steering, speed control and navigation, using foveal vision. In this manner, the driver is potentially able to achieve the simultaneous operation of driving and interacting with an in-vehicle interface. It is important to note that there are likely to be limits to the types of operations achievable using only peripheral vision, but evidence suggests that some level of interaction with an IVIS is possible via this interaction mechanism [7]. To understand more about the potential for 'non-visual' operation of in-vehicle interfaces in both scenarios described above, we conducted a driving study to investigate the extent to which motor and visual processes are used in the selection of buttons on an in-vehicle touch screen display. The study was focussed on specific scenarios in which the driver may need or want to use the in-vehicle touch screen whilst driving. However it is recognized that driving whilst performing a secondary task will be relatively detrimental to the primary task compared to solely driving [11, 19].

1.1. Background

1) Peripheral Vision

As drivers typically spend around 90% of their time looking at the road scene [2] it is important that in-vehicle displays are designed such that drivers are encouraged to keep their eyes on the road. In addition to display characteristics, such as button size [5], number of items represented on the screen and display location [3, 10], this could be achieved by exploring driver glance behaviour in order to better understand how to accommodate glance behaviour through display design.

The idea of using peripheral vision to detect information has been explored by a few authors in previous research. Horrey and Wickens [10] argued that drivers might use ambient vision (peripheral vision) to perform tasks of controlling the car such as lane keeping and speed control. However, they suggested that foveal vision might be required for effective hazard detection. In that instance, it is safer for the driver to have their eyes on the road to be able to detect hazards instead of focusing on an in-vehicle display. Summala et al. [19] conducted a study in which they asked novice and experienced drivers to drive on a straight road and use only their peripheral vision for lane keeping whilst performing a secondary task using their foveal vision. The results revealed that even though initially the novice drivers' performance was poor, it improved with practice and time. Another study carried out by Summala et al. showed that ambient vision was effective when used for vehicle control but did not support hazard awareness [20]. Lamble et al. examined the effect of the positioning of a visually demanding in-vehicle task on the driver's ability to use peripheral vision to detect a decelerating lead vehicle [14]. During this study, a forced peripheral vision paradigm [19] was used where participants were asked to focus solely on an LED display, which was positioned at 10 different locations, and use their peripheral vision in detecting the decelerating vehicle in front. The results showed a strong inverse relationship between time-to-collision (TTC) and eccentricity of the task to the normal line of sight. Another study conducted by Horrey and Wickens involved participants reading information on a head-up display (HUD) and head-down display (HDD) whilst driving in a simulated environment [10]. The results of the study showed that participants were not as successful detecting hazards on the road using their peripheral vision when they were looking at the HDD using their foveal vision. Overall, the adjacent display was the better option in detection hazards and completing the IVT task.

Most peripheral vision studies in the context of driving investigate scenarios in which the driver is interacting with the in-vehicle display (using foveal vision) and is asked to detect anything important that might be happening on the road (i.e. potential hazards) simultaneously (using peripheral vision). However, there is a lack of research exploring the potential of using peripheral vision as an interaction mechanism when interacting with in-vehicle displays. Kittiwongsunthorn et al. studied the possibility of presenting information in the driver's peripheral vision to aid the driving task without the driver having to take their eyes off the road [13]. They suggested that drivers are able to detect non-critical information that is presented in the driver's peripheral vision. As opposed to encouraging the driver to focus their attention on the in-vehicle display, it is preferred to encourage them to keep their eyes on the forward driving scene and use their peripheral vision to interact with the display. Hence the study discussed in this paper aimed to explore the use of peripheral vision as an interaction mechanism for in-vehicle touch screens instead of using it in hazard detection.

2) Muscle Memory

Muscle memory is another interaction mechanism that has not been explored sufficiently within the driving context in relation to interaction with in-vehicle displays. Muscle memory, i.e. motor learning, is defined by the Medical Dictionary as "*any of the processes related to the acquisition and retention of skills associated with movement. They are influenced by practice, experience, and memory*" [16]. In driving, the driver builds up muscle memory as they gain experience. Actions that are essential to driving such as changing gear, indicating, steering, keeping the distance to the car in front and lane keeping become more automatic. The driver does not necessarily actively need to think about every decision before executing them [1].

Muscle memory would, in theory, enable a driver to move their hand directly from steering wheel to an in-vehicle control without the need for vision. It is easier to develop muscle memory when using traditional hard in-vehicle controls as the driver may approximately know the location of the button they need to press and may then use tactile cues by touching the buttons and receiving physical feedback which helps to differentiate one from another. This is not possible with touch screen displays as they lack tactile feedback [18]. They are also dynamic compared to traditional dials/buttons, which means that button locations change between different menu screens. This makes it more difficult for the driver to develop muscle memory for specific locations on a touch screen display. However, it is likely that some muscle memory will develop to guide a driver's hand from steering wheel to touch screen and possibly to a specific area of the screen where they recall a particular button being located. This will contribute to reducing button selection times with practice and with decreasing need for vision over time. Previous literature suggests that vision is important in learning; however, it becomes less important for well-learned tasks [17].

There is also research in literature that is used to predict task time when interacting with displays such as Fitts Law [4]. Fitts Law considers the prediction of task time for expert users based on characteristics of the user interface such as target size, location, and design. A study conducted by Large et al., builds up on Fitts Law considering the visual demand measures in a driving context [15]. However, this study does not consider performance over time and/or the relationship between different interaction mechanisms in order to achieve non-visual use. The exploratory study discussed in this paper aimed to investigate the distinct contributions of peripheral vision and muscle memory to selection of touch screen buttons on an in-vehicle screen by looking at task time. Four hypotheses were proposed based on previous research and understanding in these areas:

1.2. Hypotheses

1) During muscle memory conditions task time (time to select a single button) will initially be high, however this will gradually decrease due to the muscle memory build up over a number of exposures;
2) Small button muscle memory condition will have the highest task time as this is expected to be the most difficult task which will require more effort;
3) As peripheral vision does not change throughout each condition (participants were asked to focus on the car ahead hence peripheral vision stayed constant) it is expected that task time for peripheral vision conditions (small, medium and large button size) will stay constant within each condition;
4) Overall, peripheral vision conditions will have a lower task time compared to the muscle memory conditions.

2. Method

2.1. Participants

Twenty-five (12 Female, 13 Male) participants took part in the study from Virginia Polytechnic Institute and State University (mean age = 25.5; s.d. 5.3 years). These participants were recruited using posters placed around the Industrial and Systems Engineering (ISE) department. All participants held a US driver's license and had experience driving on US roads for at least 1 year (mean time with license = 7 years; mean annual mileage = 7594 miles). All participants also had experience using touch screen devices such as smartphones and tablets.

2.2. Design

The study followed a within-subjects design. There were two independent variables; the interaction mechanism (muscle memory, peripheral vision) and button size (small 6x6cm, medium 10x10cm and large 14x14cm). As a result, all participants had to complete six conditions in total, which took approximately 40 minutes. The order of the conditions presented was counterbalanced for each participant in order to avoid any learning effects.

Throughout the study participants were asked to sit in a stationary left-hand driver driving simulator – this study did not involve any driving – and interact with the touch screen that was placed on the right hand side of the steering wheel. The touch screen task consisted of a single, white, square button appearing on the touch screen one at a time (repeated 24 times) and participants were asked to press the button as quickly and accurately as possible. Within each condition, the location and the size of the button stayed the same in order to ensure they developed some muscle memory. Conversely, between conditions the size and the location changed. Participants also heard two different sounds during their interaction with the screen; one tone to indicate the button had appeared on the screen and another to indicate that they had pressed the button correctly. This confirmation feedback ensured that motor learning would occur as participants would know to aim towards the same area of the screen on subsequent presentations of the button. As soon as the participant pressed the button, the presentation moved onto a blank screen for 5 to 10 seconds before moving onto the next button screen.

During the muscle memory conditions participants were given a pair of glasses to wear which blocked their peripheral vision (see figure 1). This meant that they had to interact with the touch screen without seeing it. However, for these conditions, participants were shown where the button would appear on the touch screen before each condition so they had an estimate of where to put their finger on the screen to press the button. During the peripheral vision conditions, a forced-peripheral technique was used by asking the participants to focus on the car in front of them which had flashing back lights and to keep their head still when detecting and pressing the button appearing on the screen [19].

Figure 1. *The glasses participants wore during the muscle memory conditions*

Participants were asked to fill out a NASA TLX questionnaire [6] at the end of each condition. The questionnaire consisted of six different measures: mental demand, physical demand, temporal demand, performance, effort, and frustration. They were asked to rate each measure on a scale of 1 to 21.

2.3. Apparatus and Stimuli

The fixed-based, medium-fidelity simulator, which is based in the COGENT Lab in the ISE department at Virginia Tech University, was used for this study. The simulator is formed of the front half of a left-hand drive 2014 Mini Cooper positioned in front of a curved screen providing approximately 270° viewing angle. One Epson PowerLite Pro G6900WU NL overhead projector was used to project the driving scenario onto the curved screen. A static image of the simulated driving environment was created using software called MiniSIM which was developed by the National Advanced Driving Simulator and the University of Iowa.

Figure 2. *Driving simulator*

As mentioned before the study took place in a stationary driving simulator so participants were not driving (see figure 2). However, the driving simulator was used to create a static driving scene image. Participants were parked on the side of the road on a motorway with a car with flashing lights in front of them. This was done to keep their focus on the car in front so they could use only their peripheral vision to locate and press the button appearing on the screen.

A Microsoft Surface 3 tablet was used to act as the in-vehicle touch screen (see figure 3). This was located in the centre console of the car to the right-hand side of the steering wheel. PowerPoint 2013 was used to create the button interface. The buttons that appeared on the screen were white squares (small, 6x6cm; medium, 10x10cm; large, 12x12cm) on a black background. The screen did not advance onto the next screen until the participant pressed the button. A sound was played when the button appeared on the screen and when the button was pressed. Only one button was displayed on the touch screen at a time.

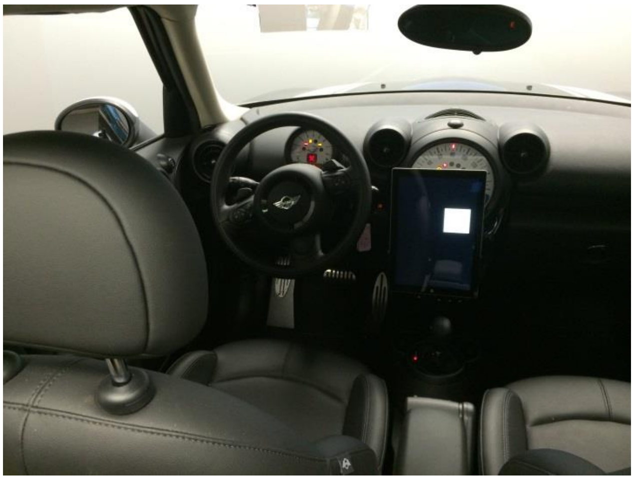


Figure 3. *In-vehicle touch screen*

2.4. Procedure

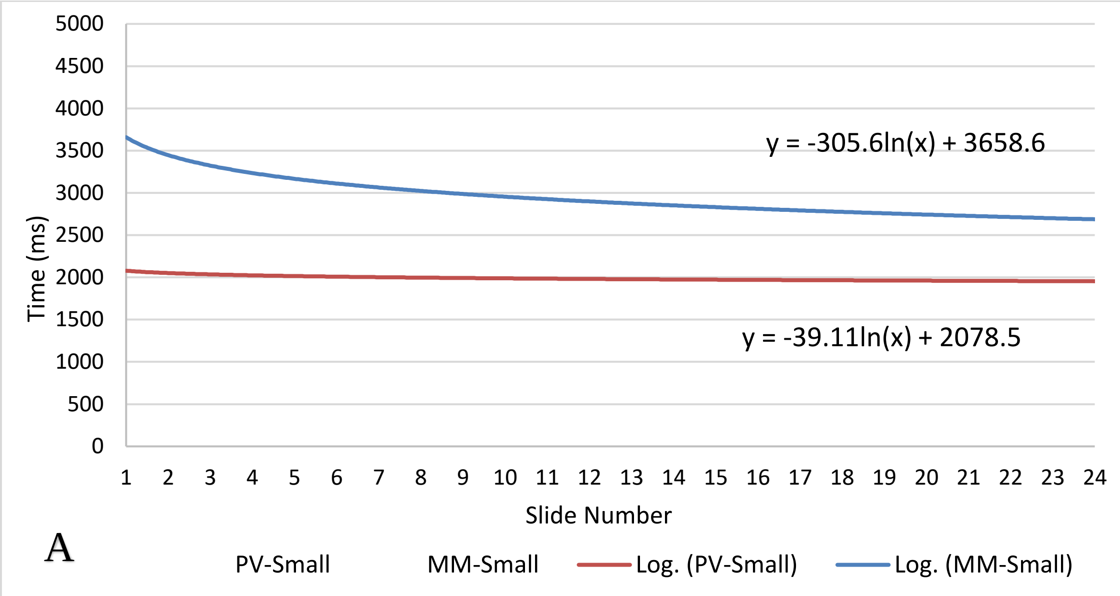
At the beginning of the study, participants were given an information sheet, consent form and a data capture questionnaire. The questionnaire was used to collect basic information such as age, gender, driving experience, annual mileage, and experience with touch screens.

During the study, participants were asked to sit in the driver's seat and to make sure to keep their focus on the car in front and to keep their head still. They were not allowed to move the driver's seat but they could adjust the headrest so they could rest their head against it comfortably to help ensure they kept their head still. They were also asked to put their hands back on the steering wheel after each button press and to use their right hand to interact with the in-vehicle touch screen. Participants were given vouchers to compensate for their time.

3. Results

3.1. Task Time

Task times were used to compare performance in the completely non-visual condition (reliant on muscle memory) and the peripheral vision condition, which comprised visual (peripheral only) and manual (motor memory) components. Although there were only 24 repetitions of the button selection task in each condition, results have been extrapolated to show the theoretical point at which it is believed that muscle memory ceases to have an additive effect on peripheral vision for button selection operations. It is likely that task times for the muscle memory condition would plateau after a certain number of repetitions and it was assumed that this would be around the point that it equalled task times recorded for the peripheral vision condition. This is because the peripheral vision operations relied on muscle memory as well as a visual component and so they represent the likely minimum time possible for completing the button selection task. The extrapolation showed this plateau point to be the 375th button press for small buttons, the 524th button press for medium buttons and the 2191st button press for the large buttons. It is likely that after the point at which the lines intersect the muscle memory task times would plateau to a constant level in line (approximately) with the peripheral vision task times.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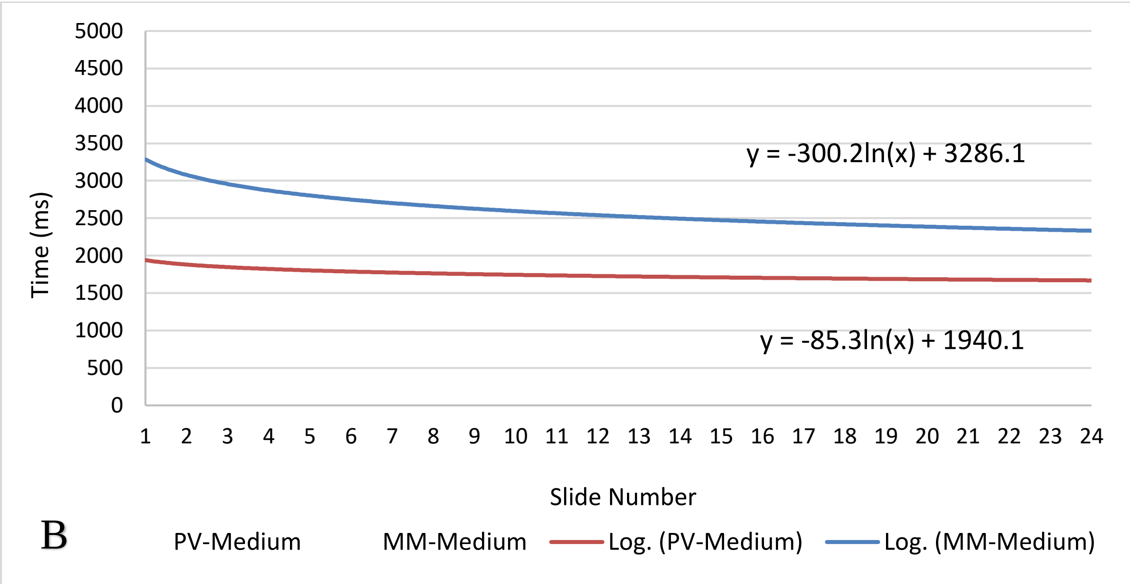
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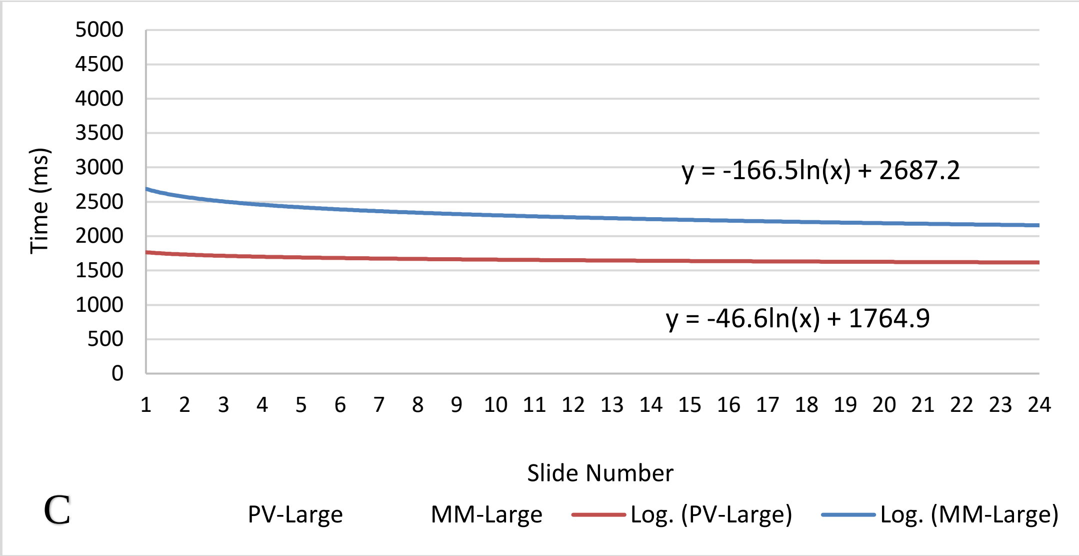

Figure 4. *Task time data for the three button sizes (A = small buttons, B = medium buttons, C = large buttons)*

The graphs (figure 4) show the trendline for task times of the two interaction mechanisms for the three different button sizes. There is a steeper decrease in muscle memory task time for small and medium buttons compared with the larger buttons. In addition, in comparison to muscle memory task time, peripheral vision task time has stayed more constant within each condition. For both interaction mechanisms, small button presses took longer to execute and they were more difficult than medium and large buttons. Although error rates were not recorded during the study, observations showed that, the number of button press attempts for small buttons was higher. Participants found it more difficult to press the small buttons in their first try.

3.2. NASA TLX

NASA TLX results show that the muscle memory small button condition was significantly more difficult and frustrating to complete compared to all other conditions. It also required more effort to complete compared to the other interaction mechanism vs button size conditions. Although a significant difference was not observed between the subjective NASA TLX measures for the other five conditions, a trend was present showing that peripheral vision conditions were perceived to be less demanding and required less effort in comparison with muscle memory conditions (see figure 5).

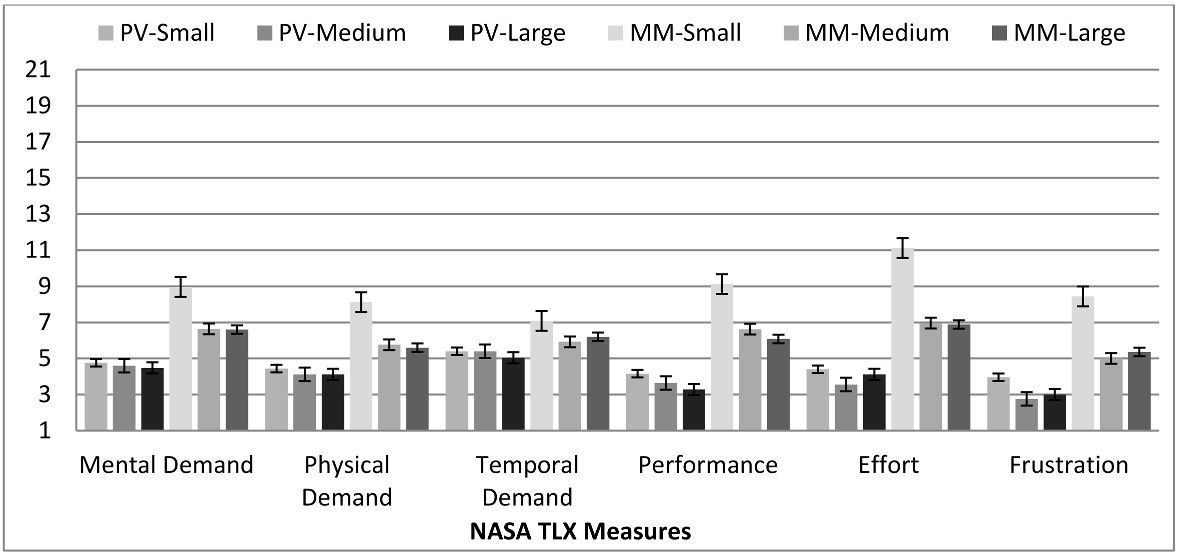

Figure 5. *NASA TLX results for all six conditions*

4. Discussion

In this paper, we studied the relative effects of two in-vehicle display interaction mechanisms; muscle memory and peripheral vision. The study also observed the effect of button size displayed on the screen on task time combined with the type of interaction mechanism. Subjective measures were collected regarding the demand of each condition.

As predicted, task time for peripheral vision conditions stayed relatively constant during the course of each condition (small, medium, large). As participants were asked to focus on the vehicle ahead, the field of their peripheral vision stayed the same all the way through. Even though there was no significant difference in task time for peripheral vision interaction between different button sizes, a trend emerged in which task time decreased as button sized increased. This was likely to be a result of participants being able to see larger buttons in their peripheral vision more easily.

An aim of this exploratory study was to investigate the human performance processes that could limit 'non-visual' operation of touch screen buttons. Muscle, or motor, memory is an important component of selection tasks and one which needs to be learned over a series of repetitions [16]. The results of this study show that for completely 'non-visual' operation of in-vehicle touch screen controls, there will be a learning effect for motor processing. There is likely to be a theoretical number of repetitions after which the practice effect disappears and the motor operation reduces to a constant duration, somewhere around the minimum task time for peripheral vision task times. For interfaces that utilise peripheral visual processing (i.e. located in a position that enables the driver to view them in their peripheral vision whilst potentially attending to the road using foveal vision) this learning effect is not evident and operation times are fairly constant over time.

This suggests that in-vehicle touch screens can be designed to utilise peripheral vision for making simple button selections. However, if in-vehicle interfaces are located outside of a driver's peripheral vision (or if peripheral vision is not available due to high demands in primary driving tasks) [8] drivers may still be able to select buttons non-visually (via motor memory), but this will be dependent on practice which may take a long time.

The results showed that the extrapolated button selection times for the muscle memory and peripheral vision conditions intersected at different points depending on button size. It is sensible to take these points as a theoretical maximum for required repetitions (after which practice no longer has an additive effect on operation time) because the smaller buttons represented the more difficult tasks and therefore represent a theoretical 'maximum' limit to performance. It would be expected that for larger buttons the number of practices required to reach a constant operation time would be lower; however, the results for the large button size condition contradict this. This may have been due to the large button press task being too easy for any learning effects. Hence, task time was also relatively constant for large buttons compared to small and medium buttons. Large buttons also covered a larger surface area on the touch screen, which meant that participants were not necessarily pressing the same spot on the button repeatedly but still making successful selections. This may have been another reason why there was a smaller learning effect observed for large buttons in the muscle memory condition.

Also as the numbers show, the number of repetitions it would take for muscle memory to intersect with peripheral vision is very high. This shows that realistically the use of muscle memory to achieve non-visual interaction would not be efficient. The extrapolation of the data also assumes that the driver would be pressing the same button repeatedly for the given number of times. However, in a realistic driving environment the driver would not be required to press the same button uninterruptedly that many times.

The results of this study are limited to single button selection operations. It is likely that more repetitions would be required to reduce the effect of muscle memory to a constant level when more buttons are present on a single screen, as participants would need to 'memorise' which button was in which location. This limits the usefulness of these results for designers of in-vehicle touch screens, but we believe that this study has shown the potential for in-vehicle interfaces to be located in the periphery and highlighted the learning effects associated with completely 'non-visual' button selections. However, it is acknowledged that using focal vision to locate the buttons would likely have reduced task times further.

5. Conclusion and Future Work

Overall, the results of the study show that it is possible for drivers to interact with in-vehicle touch screens using peripheral vision. With this knowledge in mind these displays could be designed to accommodate peripheral vision interaction in order to encourage drivers to keep their eyes on the road. For example, drivers could be given the option to customise their touch screen so that the icons for commonly used functions during driving are on the side of the touch screen that would allow peripheral vision interaction.

Further analysis of the data will be conducted to investigate error rates by looking at the number of attempts it took participants to press each button. Additional investigation will include the effect of foveal vision on task time alongside peripheral vision and muscle memory. The effect of driving in conjunction with the different types of interaction mechanisms on task time will also be explored. In addition, the results obtained from a previous study in which participants were asked to perform a single button press on a touch screen [3] involving several variables such as button size, button location and contrast levels will be used in conjunction with the results of the current study. The results of the previous study showed that some participants were able to perform the task non-visually. The study discussed in this paper aimed to explore the interaction mechanism that may have been adopted by these participants. Future work aims to identify a combination of appropriate interface characteristics (colour, number of buttons, contrast, etc.) that would accommodate peripheral vision interaction, which potentially will result in drivers not taking their eyes off the road when interacting with such systems. Further investigation could also consider how generalizable the results from the current study are for physical buttons where peripheral vision and muscle memory are still involved as interaction mechanisms as well as non-visual feel aiding the locating of the controls.

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