The Impact of Tangibility in the Input of the Secondary Car Controls: Touchscreens vs. Physical Buttons

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Abstract. The way car controls are displayed has been changing over time, as physical controls are being replaced by touchscreens and touch interfaces. This allows the creation of a more clean and aesthetically pleasing interface and reduces costs, but also creates the potential to increase the drivers' distraction and error as controls may be harder to find and use. This paper presents an evaluation of driver performance in the context of a laboratory simulation of an in-car, on road driving study, that compares driver reaction time and number of errors while using physical buttons versus a touchscreen interface. The study was conducted with 20 participants, performing the same tasks in both simulations but with different interfaces. The results concluded that the type of interface impacts reaction time and greatly impacts the number of errors made by the driver in it, as well as, in the road. The data analysis showed that the reaction time to the touch screen was significantly higher and 80% of the participants commited errors in it, compared to only 20% on the physical buttons. The driving performance of the participants was also substantially impacted by the touchscreen, when compared to the response pad. These results raise important questions about the fact that touchscreens are not the best solution in terms of safety. It is true that in terms of possible configurations, touchscreens give great freedom to car manufacturers, but at the expense of road safety.

Keywords: Touch input · Touchscreens · Multitasking · Mental workload · Driving performance · Road Safety

1 Introduction

In recent years, in-car controls have been changing from traditional buttons in the central panel of the car to touchscreens and touch-sensing interfaces. The changing of these interfaces allows designs to be "more aesthetically pleasing, flexible and dynamic" [1] and requires a smaller space in the car panel. On the other hand it creates the potential to increase the driver's distraction and errors while driving [1].

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Lee and collaborators [2] defined driver's distraction as "diversion of attention away from activities critical for safe driving towards a competing activity". Also, existing literature has shown that "both cognitive and visual distraction can impair the driver's reaction time behavior" [3].

Driving is a complex dynamic performance in which the driver is required to accomplish several tasks at once, so that drivers must be able to handle both speed and heading while planning the route to their destination and trying to understand and predict the trajectories of other cars and the intentions of their drivers, this resulting in a substantial mental workload while driving [4]. Mental workload can be defined as the proportion of information processing capability used to perform a task [5].

Considering the difficulty of the driving task and the quantity of information that drivers have to process and manage inside and outside of the car, there are multiple factors that contribute to the triggering of the driver's mental workload. The introduction of the touchscreen monitors in the central panel of the car contributes to an increase of information inside of the vehicle, resulting in increased levels of complexity in the driving task, as the driver has to increase its distribution levels on the visual and auditory resources [6], leading to paying less attention to the actual task of driving.

Given the different types of people that drive cars nowadays, mental workload cannot be seen as something stable and equal to everybody, as different drivers have different approaches to driving problems and it also depends on their performance ability, the workload may differ from person to person, but the truth is that more stimuli result in a higher mental workload [7], resulting in less attention to the road.

Mental workload while driving is directly linked to performance of driving and task demand [7] so the more complex the task while driving, higher is the mental workload required to continue driving, and the lesser is the performance ability to drive. So the complexity of the task to be performed in the secondary panel of the car has a direct impact in the driving attention of the driver and the secondary tasks of the car must be handled in a way that they have the smallest impact possible in the driver's driving performance.

This study aims to test if a physical interface results in a lighter mental workload for the driver, allowing them to focus more on the primary task of the car—driving; leading to safer driving. This is based on the fact that touchscreen panels allow the user to perform a lot more tasks, increasing task demand and posing a threat to the driver's attention to the road, given that more tasks result in a higher mental workload that as referred ahead is directly linked to driver's performance of driving.

To further defend this hypothesis it has to be taken in consideration that touchscreens not only allow the user to change the objective of the task on the screen and allows them to distract with other less important tasks but also always maintain their position and format even if their task changes, creating a difficult environment for the driver to memorize the tasks available in the panel or sensing the place where the driver has to perform the task. On the other hand physical panels have a permanent and tangible 3D format that can be sensed by the drivers and memorized by them thought their haptic senses [8], therefore creating a haptic memory of them [9] and making the task more mechanical and automatic [4] in a way that it decreases the mental workload of the task [7] and also allowing drivers to maintain the visual sense focused on the road and other more important tasks.

2 Methodology

This study evaluates the difference in driving performance while a driver presses physical buttons versus buttons on a touchscreen, as a secondary task. The main stimuli is the driving of the vehicle, which was tested using a racing simulator, and requires the person's visual and motor skills. The secondary task, which occurs at specific locations in the track, also requires the same level of attention, as the driver must take his right hand off the wheel, and in some cases look at the dashboard in order to press the correct button (physical or on a screen).

The shared stimuli can contribute to a triggering of the driver's mental workload, and therefore cause performance issues, which could lead to a road accident. How different interfaces can affect the driving performance and which one is safer to use were evaluated by measuring the reaction time to press the button as well as the mistakes made in it and the driving performance.

2.1 Experimental Conditions

As an independent variable, the type of interface were defined as the "secondary controls" was switched between physical buttons and a touchscreen, as a stand-in for what would typically be found in a car's dashboard, such as A/C and radio controls. The dependent variables are the driving performance of each participant as well as the number of errors committed in the interface and the reaction time to it.

In the first testing phase, each participant drove through the circuit until they felt comfortable with the racing simulator and its main inputs—the steering wheel and foot pedals. The virtual car was in automatic mode, meaning there was no need for changing gears and the participant only had to accelerate, brake and turn the steering wheel. This phase would normally take one lap or more, depending on the person, and it was not for evaluating purposes. Its purpose was to assure the participants had a basic understanding of how to drive the car without making mistakes, in order to establish a common baseline to every participant. When the participant felt confident enough and the experimenters determined that the participant met the requirements, the evaluation began by introducing the secondary task, pressing specific buttons on an input device while driving at the same time. There were 35 events in which the participant had to press a button, and in order to know which button to press he had to hear a sound file playing the name of the color of the button, with five available options: blue, red, green, yellow and white. The sequence in which these sound files were played was initially created in a random generator (random.org) and then played in the exact same order for every participant as the events in which the participant was required to press the buttons were exactly the same as well. The lap was completed twice, once with a physical input, and again with a tactile input. The order of interfaces presentation was counterbalanced.

2.2 Participants

A convenience sample was selected, mainly composed of members of the Faculty of Architecture of Lisbon University academic community. In total, there were twenty participants (eighteen students and two professors), ranging from 20 years to 63, with an average age of 27 years old. Fourteen identified as female, five as male and one as non-binary. We also inquired about whether they had a driver's license, whether they drove regularly and what kind of input was used for secondary controls in the car they usually drive in. Concerning driver licence, 14 participants had it, and from these 8 drove regularly, and 4 of the late had some experience with a touchscreen in their car.

2.3 Tools

In order to perform the tests, a racing simulator was used, specifically the Assetto Corsa videogame, which, due to its advanced physics engine, provides a "a very realistic driving experience" according to the game's Steam store page. This simulator was run at max settings at a resolution of 1920x1080 and at a frame rate of 60 frames per second, on a desktop with Windows 10 (i7-6700 CPU @ 3.4 GHz, 16 GB and a GPU Nvidia GeForce GTX 1080 16GB). To control the car in the simulator, a Logitech G29 steering wheel and pedals served as input. This steering wheel provides a high degree of sensitivity, which allows for precise control of the car, as well as force feedback to more accurately represent real driving.

To test the difference between the tactile (touchscreen) and physical (buttons) input method for the secondary controls, a Lenovo tablet computer running on Microsoft Windows 8 was used for the former while a Cedrus RB-530 response pad (Fig. 1) connected to a MacBook Air 2020 was used for the latter. Dimensions and color of the buttons on the Lenovo Tablet was adjusted to be similar to those one of the physical response pad. Secondary task stimuli was controlled with SuperLab.6 and SuperLab.5, for the response pad and tablet respectively, which allowed us to collect data on which button was pressed for each event in which the participant had to react, as well as their response time. This program was also used to provide the sound stimuli that informed the participant on which button to press.

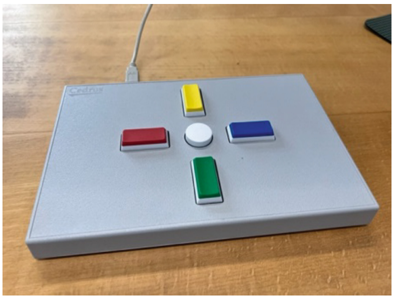

Fig. 1. Cedrus RB-530 Response Pad

2.4 Procedures

This experiment took place in the ergoUX Lab of the Faculty of Architecture of Lisbon University, in December 2022. Preparations began by setting up the simulator and inputs. The steering wheel was fixed to the table, and its position was marked with tape, to guarantee a secure position. The foot pedals were right below the desk the steering wheel was attached to, but these were not in a fixed position, so the participant could adjust them to their preferences, in order to make the experience as comfortable as possible. The computer monitor was also at a constant position marked with tape, as was the stand that supported the response pad and the tablet. This stand served to position these input devices at a comfortable angle, and to facilitate the exchange of one type of input with the other.

Afterwards, several students and faculty members were personally invited. Once they arrived at the lab, participants were asked to sit comfortably in a designated chair, and adjusted the distance between the pedals and the seat. The participant was instructed to have their arms slightly bent, as well as their knees and their back and head straight.

After having the setup ready, the participant was informed on the details of the overall experiment, how it would require around half an hour to be concluded, and how it would be organized in three different phases, the first one for training purposes and the latter two for performance evaluation moments where the screen would be recorded. Then, the participant was asked if they had any driving experience, and if not, the pedals' functions were explained in more detail, in order to provide some assurance. Afterwards, the participant was informed about the rules they had to follow in the first phase, which were to drive on the right side of the road without going over the line, and to maintain a speed below 100 km/h, reinforcing the idea that the objective is not to be the fastest but to drive at a speed in which the participant feels comfortable. The participant would start to drive while the two test experimenters prepared for the next phase and observed their behavior. If the participant finished the first lap and proved they could drive according to the rules, they could pass to the next phase. If not, they were asked to drive until these requirements were met. The experimenters would then position themselves behind the participant, and the test would ensue.

One of the experimenters had the task of comparing the current position of the participant on the track with the 35 defined events where the sound file must be triggered, and the second one had the task of triggering the actions, and of creating and saving the files in SuperLab and recording the screen. Whenever an activation point was reached, the first experimenter gave a sign to the second experimenter, imperceptible to the participant. The second experimenter would then trigger the event in SuperLab. The software then recorded the reaction time and the participant correct or incorrect response. Each test took, on average, around 30 min to complete. At the end of the experiment, before leaving, the participant filled out a small form with the information mentioned previously. The participant's name was not recorded and participant consent was required. Figures 2 shows the experimental setup with a participant testenig with the touchscreen.

Fig. 2. Participant testing with the touch screen in the experimental Setup.

2.5 Data Processing

Everything directly related with the secondary controls inputs, the touchscreen and response pad, was recorded using SuperLab. This means that it was only necessary to copy these results to a spreadsheet.

Fig. 3. Reference frame overlaid in the simulator

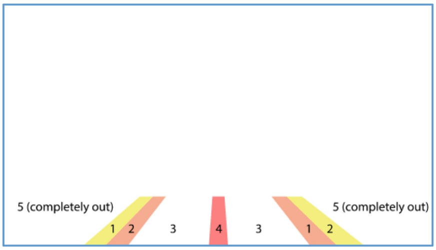

Fig. 4. Reference frame guide

Dealing with driving performance wasn't as straightforward. To check if participants were going outside the lane or speeding, this had to be done manually by reviewing a video recording of the simulator and marking how many times these errors were committed for each participant. There were 5 levels of driving outside the lane, which were identified by overlaying an image on top of the video recording with markings for each kind of error (Figs. 3 and 4), based on tire path and third-person view examinations.

3 Results

Results were treated considering three types of data: secondary controls reaction time (Fig. 5), secondary controls errors (Table 1 and Fig. 6) and driving performance (Fig. 7).

To define driving performance, a Driving Error Score was calculated using a formula based on the 5 levels of driving outside the lane, and speeding: Number of times going outside the lane (level 1) + (Number of times going outside the lane (level 2) * 2) + (Number of times going outside the lane (level 3) * 3) + (Number of times going outside the lane (level 4) * 4) + (Number of times going outside the lane (level 5) * 5) + Number of times speeding (Speed > 100 km/h). This formula weighs errors that are more severe more heavily. Going completely outside the lane increases the score much more than only going slightly outside the lane.

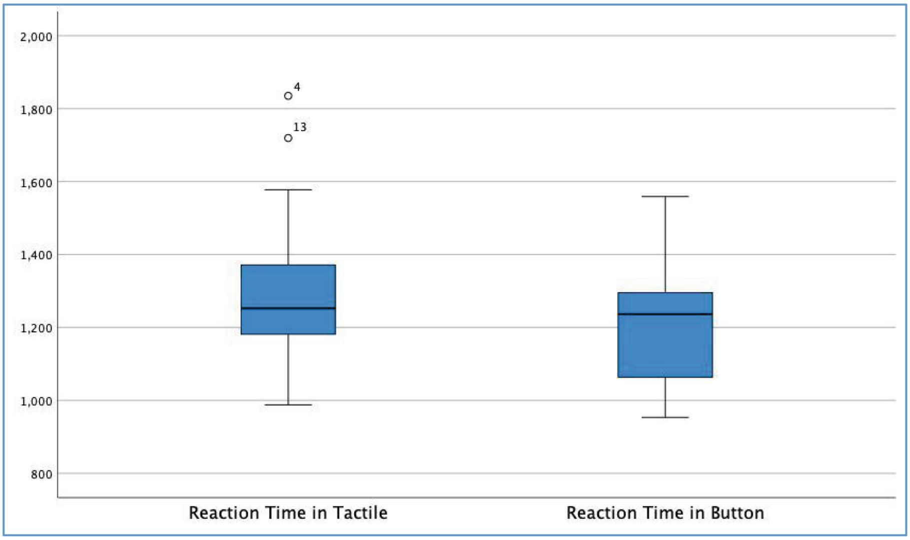

Fig. 5. Reaction time for the tactile interface and the physical interface with buttons.

In order to understand the difference between driving performance for the tactile and physical interface, the averages of the reaction time and errors were calculated for all 35 events for the total of 20 participants in our study.

Table 1. Percentage of errors for the physical and tactile interface.

Number of error	Response Pad (Physical interface)	Touchscreen
0	80%	20%
1	10%	30%
2	10%	20%
3	0%	20%
4	0%	10%

From the average of all 20 participants a comparison was made between the distribution of time and errors for the two conditions. Since the distribution of time and errors was not normal, the non-parametric Wilcoxon test for dependent samples was chosed. The Wilcoxon test revealed the existence of a statistically significant difference, for reaction times ($z = -2.277$; $p < 0.05$), for errors ($z = -3.247$; $p < 0.001$) and for the driving error score ($z = -3.283$; $p < 0.001$). Figure 5 illustrates the distribution of times and Fig. 6 illustrates the driving error scores. Table 1 illustrate the number of interface errors committed in the form of a percentage of participants. Figure 7, displays the calculated driving error score for each participant, also for both the response pad and touchscreen.

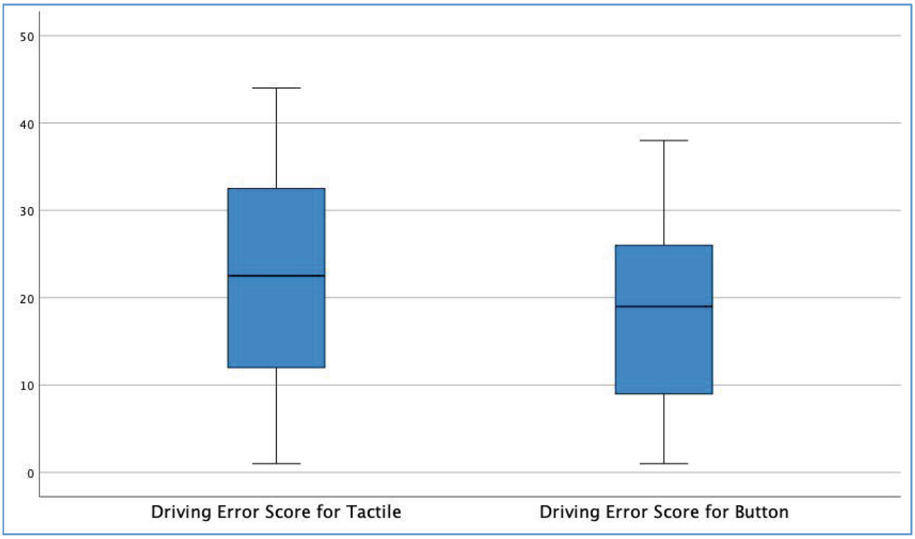

Fig. 6. Driving error score for the tactile interface and the physical interface with buttons.

4 Conclusions

Overall, the type of interface impacted reaction times and greatly impacted the number of errors in the interface. On average, participants' reaction time was 96 ms longer with the touchscreen than with the response pad, without removing incorrect presses. As can be observed in Table 1, 80% of participants never pressed the incorrect button when interacting with the response pad, while inversely only 20% made no mistakes with the touchscreen. These results are, on their own, significant when it comes to road safety. Not only does the extended reaction time increase the amount of time in which the driver's attention is divided between tasks, but also the large amount of errors can result in longer periods of divided attention, since the driver would need to rectify the mistake. It also puts in question the effectiveness of a touchscreen interface as a viable replacement for physical interfaces, since it results in more errors.

When it comes to actual driving performance, there was a substantially larger amount of errors made while using the tactile interface for the secondary controls (Figs. 6 and 7), which means that greater reaction times translate into poorer driving performance as hypothesized. It can also be inferred that tactile interfaces require more attention from the driver.

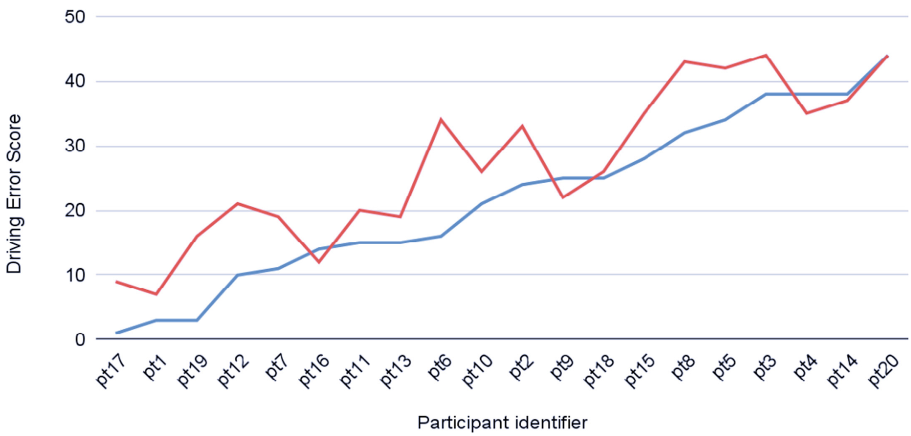

Fig. 7. Displays the calculated driving error score for each participant, also for both the tactile interface (Touchscren – RED) and the physical interface (Button - BLUE).

Results show that the use of a tangible interface results in safer driving, less prone to errors in the secondary controls as well as on the road. However, there are many more ways in which data that was extracted in this study could be analyzed. In the future, it could also be interesting to check how removing incorrect presses would impact the data (e.g. a participant could have a faster response time with the touchscreen but press the wrong button, which, in the way the data has been processed so far, would result in more positive results for the touchscreen), or how the difficulty of driving in each event could impact reaction times and errors. At a time when the industry in general, and the automotive industry in particular, are investing more and more in touchscreens, these results raise important questions about the fact that they are not the best solution in terms of safety. It is true that in terms of possible configurations, touchscreens give great freedom to car manufacturers, but at the expense of road safety.

To properly frame the results and conclusions of this study, some limitations to be resolved in future studies must be highlighted. The sample should be increased both in its dimension and in its diversity, seeking to heterogenize the sample also in terms of more diverse age groups.

The use of the simulator, based on a game computer platform, also constitutes a limit of this study. The 35 events (secondary stimuli) were activated by two experimenters. One who kept his attention on the route and at the right time for each event gave a touch to the other experimenter who triggered the secondary task. In a driving simulator dedicated to the study of car driving, this management is done automatically, always in the same place and moment. Naturally, when we pass this management on to the experimenters, we can introduce small spatiotemporal variations at the beginning of the secondary stimulus, which despite not being significant for the results of the study, deserve to be mentioned as a limit of the study.

Naturally, a driving simulator also gives automatic outputs of driving performance. In the case of this study, the performance evaluation required an analysis of all recordings of the experiments in order to properly evaluate the driving performance, which was a very time-consuming process and is not free from the possibility of error.

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