School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Are touch screens the new mobile phone? The effects of touch screen devices in vehicles on distraction and driving behaviour

Nguyen Do Duc Khanh

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :
Prof. dr. Tom BRIJS

CO-SUPERVISOR :
dr. Ariane CUENEN

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Preface

The present report is the outcome of Mater Thesis Course of the Master of Transportation Sciences in Hasselt University. The objective of this thesis program is to investigate the impacts of a touchscreen system in the cars on driving performance and driver workload while driving. The practical outcomes could help the auto manufacturers and policy makers on how to improve and make the system to be more friendly and safely with the users.

In this master thesis course, I had opportunities to collaborate with Prof. Tom Brijs and Dr. Ariane Cuenen as my supervisor and co-supervisor from the Institution of Transportation Sciences, Hasselt University. During the thesis period, although in a short time, I have the opportunity to integrate consultations and instructions from both supervisors into my research.

In the first stage, both supervisors gave me insightful guidance to formulate the topic of the thesis, then come up to a plan approach of the thesis topic. My thesis topic is to investigate the impacts of using an in-vehicle touchscreen infotainment system while driving on driving performance and driver's workload. After constructing the framework, literature review was conducted to find the missing gap of previous studies, then coming up with an appropriate research methodology. A driving simulator study would be a suitable and practical approach to investigate the research problem. The results after data analysis process is to formulate recommendations towards vehicle manufacturers and policymakers to improve user experience and road safety. In addition, the risk of using a touchscreen while driving should be informed to the drivers by advocating campaigns to raise the awareness of drivers about adverse effects of the touchscreen.

In compiling this report, I have intended to bridge the gap between theoretical and practical approaches, convey a research study to implementations in the real world. That is also the main purpose of this thesis course. With these objectives, I have tried to compose this thesis report in an enlightened and condensed form, in order to deliver all relevant information of the thesis report to the reader in a short time. As I had completed my thesis within a short period of time so the study could not avoid some limitations and errors. I apologize if any mistake is found which was not deliberately made. Any comment and suggestion are truly helpful and valuable for me in the future studies.

Lastly, I will have to thank to Prof. Tom Brijs and Dr. Ariane Cuenen in Uhasselt, Belgium. I really appreciate for their help and supervision. In addition, thanks to Bart Devos and Thomas Stieglitz to help me in simulator settings and technical assistances during conducting the experiments, without these assistances I could not carry out and finish this master thesis course. I hope in the future, I could have other opportunities to collaborate with both my supervisors in other studies.

Summary

With an era of autonomous and connected vehicles, infotainment system is becoming more and more prevalently in a modern car. To adopt this movement of car technology, automotive manufacturers have employed a touchscreen interface in the dashboard of the car. With combination of a new touchscreen display mounted in the middle of the dashboard, the new infotainment system gives passengers more technology experience and assists them in both driving performance and multiple media purposes. However, according to scientific articles, a touchscreen infotainment system could pose some threats to drivers such as distraction which is considered as cause of many accidents on the road when the drivers.

A driving simulator research with a NASA-TLX survey was proposed to investigate the possible negative impacts of the touchscreen on driving performance and subjective workloads. From the previous studies, there were several research already carried out to investigate about the driving performance impairment of the infotainment system in the vehicles. However, limited research have been done specifically in the impacts of a touchscreen system which is now become prevalent in the modern cars.

After preparing a proper plan and setting the driving simulator, during two week of experiment thirty-six participants had been took part and completed the simulator tests. The collected data showed that driving performance of drivers significantly degraded when committing touchscreen tasks while driving with a lower average speed and higher standard deviation of lateral position. Specially, in critical events such as pedestrian suddenly crossing the street which required more attention ability, the drivers tended to be failed in pedestrian detection and stopping in front of them. The percentage of performing successfully a touchscreen task during driving was affected by both types of driving tasks and types of roads. This results implied that the driver conspicuously compensated between touchscreen usage and safety. In addition, driving performance impairments could be predicted by driver's background such as their experience in using the infotainment system in the cars and in driving, and gender of the drivers. Based on driver's perspective, most of drivers considered using a touchscreen system in the cars while driving could cause them more mentally, physically, temporary demanding and effortfully than normally driving.

The study results complement to the past research that any sources of stimuli could affect driving performance in some extend of degrees. Hence, more research should be launched to have more evidences of negative impacts on driver's attention and driving performance. The study supports car manufacturers and policy maker have better improvements of the touchscreen system in reducing safety risks due to distraction from the touchscreen. Practical campaigns in training and raising awareness of the drivers could be an ideal to mitigate these potential risks from the touchscreen system.

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Master's thesis

What is the effect of the use of touchscreen while driving on workload and driving performance of drivers?

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Abstract:

In the era of electric vehicles, a large LCD multi-touchscreen display has been widely featured on the dashboard with a better interior aesthetics and more functionalities. However, using a touchscreen infotainment system in the cars is considered a source of visual-manual distraction that could endanger the driving. This study aims to investigate the effects of an in-vehicle touchscreen on driving performance and driver's workload while driving. In a fixed-based driving simulator, thirty five drivers with a valid typed-B driving license completed two simulator experiments: driving with touchscreen tasks and without touchscreen task. Driving performance (average speed, standard deviation of lateral position (SDLP), headway, braking distance, crashes) and touchscreen performance (success, miss and fail rate) measures were recorded while driving with and without touchscreen in different zones (50, 70, 90 and 120 km/h). In general, drivers tended to drive slower in all types of road while employing the touchscreen compared driving without the touchscreen. There was no statistically significant evidence of maneuverability impairment, except in urban road with speed limit 50km/h with higher SDLP when the drivers using the touchscreen. In addition, when responding with critical events such as pedestrian crossing the street, drivers failed more in pedestrian detection with touchscreen tasks, however, braking distances and crash number with the crossing pedestrian were the same. Touchscreen task performance depended on main driving tasks and types of roads (highway or urban road). Lastly, based on subjective workload of drivers after each drive, the drive with touchscreen employments could cause drivers more mentally, physically, temporally demanding and effortfully than the normal drive without touchscreen. From these results, auto-manufacturers and policy-makers should implement multiple approaches such as improve the touchscreen design to be more friendly and safer with the users, as well as raise driver's awareness and train them in using a touchscreen while driving.

Highlights:

- In critical events, crossing pedestrian detection rate of the drivers while using the touchscreen was lower than no touchscreen usage, but braking distance and crashes with the pedestrian were not changed in-between no and with a touchscreen.
- Driving performance of drivers was significantly impaired with lower average speed in using a touchscreen, however the standard deviation of lateral position did not change except in urban areas.
- Driving performance impairments could be predicted by driver's background such as their experience in using the infotainment system in the cars and in driving, and gender of the drivers.
- Touchscreen task performance was influenced based on main task driving and types of roads.
- The drivers basically experienced over workload to drive in touchscreen tests than normal drive.

Key words: Touchscreen, Distraction, Driving simulator, Attention, NASA-TLX.
Word numbers: Approx. 19,000 words.
Tables: 8
Figures: 20

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1 INTRODUCTION

1.1 Background

The automotive industry nowadays is becoming more competitive and developed among plenty of car manufacturers. Specially in the era of technology, the automotive makers attempt to apply more and more new technologies in the new cars to compete with other brands and attract more customers. With the availability of the new technical innovations, multiple of new features, functionalities, and services have been constantly added in vehicle systems. Advanced driver assistance system (Sakikala & Ramesh, 2018), energy management, interconnected vehicle network (Broy et al., 2007), car telematics system (Yoo, 2010) are some of prominent features currently developed and applied in car technology industry. All those new technologies are integrated with a traditional infotainment system to enhance driving performance and safety of users. The infotainment system in vehicle is employed for the vehicle to communicate with the drivers.

1.2 Touchscreen infotainment system introduction

1.2.1 Definition of touchscreen infotainment system

Infotainment system in vehicle is defined as a mash-up of two its main functions “Information” and “Entertainment”. Basically, the infotainment system gives drivers from multiple media functions such as calling, texting, radio, music, navigation… to system operation such as vehicle information, safety system, climate adjustment…The below figure is an example of a touchscreen infotainment system

FIGURE 1 An example of an infotainment system

1.2.2 Popularity of the touchscreen infotainment system

With more expensive and luxurious vehicles, the drivers can expect more features, more interferences with the system. A display of the infotainment system is mostly mounted on the dashboard in the middle of the car. In each new modern car today has its own infotainment system with different interfaces, designs, and features. For instance, Kia UVO from KIA, Korea; Mercedes-Benz MBUX from Mercedes, Germany; or Ford Sync from Ford are several examples of the infotainment system of current car models. Even though with a variety of infotainment operation system, but the communication methodology between users and the system is mostly via a touchscreen display interface with no or less physical buttons than traditional system. With more functionalities and features in the cars, most of car manufacturers employs a touchscreen display for drivers to communicate with the vehicle because of many advantages from a touchscreen.

1.3 Advantages of a touchscreen infotainment system

1.3.1 Improving driver experience with infotainment system

As the number of functionalities is increasing dramatically by days and physical buttons could not handle that much of complex and informative tasks to compared with a display, hence touchscreen display has been used to encounter that problem of physical buttons. When it comes to assess a technical system, specially in a vehicle, usability is one of the most importance factors that represent its success (Kessels, 2021). Two key indications of usability: adaption rate and task completion time have been evaluated. Firstly, there is a direct relationship between hand gestures and eye movement towards the display (Dul and Weerdmeester, 2001). And a touchscreen display can provide a clear and higher quality of functionality visualization in the cars. It helps the users to interact with infotainment features instantly intuitively in the car, even for novice users to learn. Consequently, once drivers enter their car, they would be adaptive quickly with the system then will not take long time to learn a new system. Secondly, research has shown that secondary tasks are performed significantly faster when compared to rotary controller and touch pad (Harvey et al., 2011). Even compared to other more modern interface techniques such as gesture interaction or voice recognition, touchscreen interaction performs equal (Rydström et al, 2005).

1.3.2 Improving aesthetic element of the vehicle interior

The next reason why car makers utilize touchscreen in most of their products, it is because of aesthetics factor. In term of design perspective, decluttering physical button or reduce the visual overload and complexity of dashboard and interior is now the tendency of technology industry. Instead of stepping in a car with multiple knobs, buttons on the dashboard and around the vehicle, now by only occupying a touchscreen in the middle of the dashboard could enhance the aesthetics and create a calm-looking environment for both drivers and passengers, then increasing their comfort and satisfaction. Nowadays, many cars having a big touchscreen are identified as futuristic vehicles by majority of customers, therefore, there is no car brand want their cars to be equipped with a small or no touchscreen.

1.3.3 Financial aspects

Cost is also a matter that the manufactures must be considered when manufacturing in an industrial scale. The touchscreen is straightforward as a part of design than a dashboard with plenty of buttons, knobs, or screen. Therefore, a standardized touchscreen helps them to minimize the development cost through years of car revolution. In additions, the new cars could be stayed modernized by only updating the user interface design, adding new applications or resize the touchscreen. For example, Tesla has pointed out that their new touchscreen display in Model S has been introduced by only updating the user interface, thus delay an expensive redesign of interior.

1.4 Problem of touchscreen system

1.4.1 Distraction from touchscreen display

However, interaction with the infotainment system in the vehicle while driving is assumed as a secondary task which is consider leading to driver distraction according to National Highway Traffic Safety Administration (NHTSA, n.d.).

1.4.1.1 Definition of driving distraction:

As definition from Lee et al. (2009) that driver distraction is a diversion of attention from critical task to secondary tasks. According to National Highway Traffic Safety Administration (NHTSA) (n.d.), all secondary tasks including talking or texting on the phone, eating and drinking, talking to people in the car, using the infotainment system in vehicles, which divert driver attention from driving tasks are assumed as leading to driver distraction.

1.4.1.2 Crash due to driving distraction.

Driver distraction is recognised as a factor of causing a collision on the road. Research from the European Commission stated that 10-30% of road accidents in Europe related to driving distraction (Ramnath et al., 2020). In addition, driving distraction was involved 17 percent of (an estimated 899,000) crashes in the USA from police report (National Highway Traffic Safety Administration, 2010). Likewise, reported data from Canada witnesses that 21% of total fatalities and 27% of severe injuries implied driver distraction (Transport Canada, 2021). With the increase in number of new technologies and functionalities developed through the years, as an observation has been studies showing that about 80 per cent of car innovations coming from computer system (Broy et al., 2007). Therefore, in the future, more and more new applications and features will be installed increasing significant interactions from the drivers with the infotainment system and the driver’s focus on driving task would be decreasing relatively (Kern & Schmidt, 2009) causing potential crashes due to driver distraction.

1.4.1.3 Type of driving distraction.

The distraction can be started from outside and inside the vehicle such as other road users on the street or using smartphone, the distraction can be categorised into various types (NHSTA, 2010; Li et al.,2017):

- **Visual distraction:** require driver to look away from the heading road to pay attention to other objects.
- **Auditory distraction:** require driver to hear or overhear other resources besides driving task.
- **Manual distraction:** require driver to take off their hand away from steering wheel to do other tasks.
- **Cognitive distraction:** require driver to mentally divert from driving tasks.
- **Auditory-vocal distraction:** require driver listen to voice output and provide auditory feedback such as calling task, talking with car by voice recognition system.
- **Visual-manual distraction:** require concurrent resources from driver including visual, manual, and cognitive engagement.

2 LITERATURE REVIEW

In this section, multiple available studies will be reviewed in the context of discovering the impacts of touchscreen display as well as the general infotainment system on driving behavior of human, particularly in driver attention and driving performance.

2.1 Theory of driving task and attention distribution on secondary task while driving

2.1.1 Driving task process

Before looking into the relevant references of touchscreen display, driving behavior is a terminology of traffic which is seemingly familiar with all readers, however, understanding about the mechanism of driving behavior is still scientifically unclear with most people. Therefore, firstly a brief introduction and explanation of driver behavior will be illustrated for the readers to have a better of how the driving process works and then how distraction could affect driver's attention and performance.

According to (Janssen, 1979), driving task is a decisive system from the drivers and it consists of three levels of decision-making process: Strategic level, Maneuvering level and Control level. Each level has their owned functions of driving tasks. The top-level is strategic level or planning level, which explains decision of a person to drive or choose the means of transport (a car, a motorcycle or other means), the route to reach to the destination, time to go, or other activities during travelling. In the second level, the tactical or maneuvering level implies the ability of driver to drive the vehicle safety and efficiently such as making an appropriate turning at the curve or overtaking one or multiple other vehicles with proper speed, distance, and maneuvering angle. The last level of driving ability is control or automatic level, which means to natural actions of driver no need to consciously or highly concentrated to perform when driving such as accelerating or decelerating actions, changing gears, braking, etc. These actions of drivers are more simplistic to compare the second level of driving task process, it becomes like natural responses while driving of the drivers. Model of driving decision process is shown in the figure above.

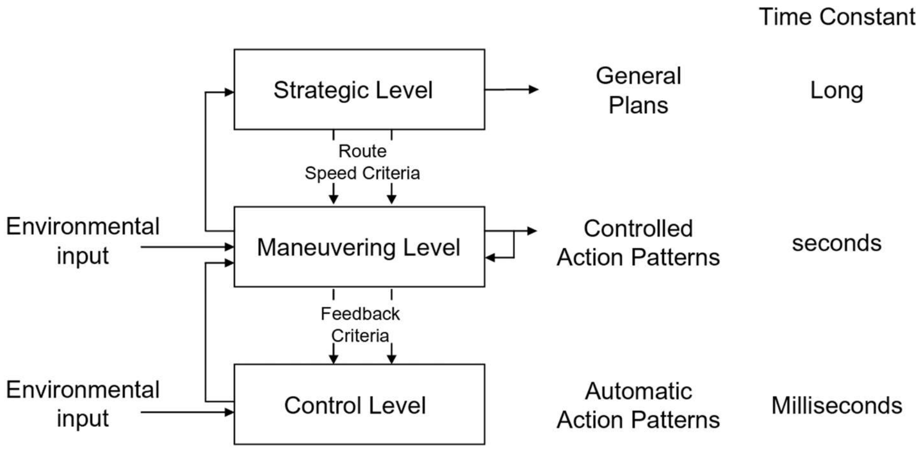


FIGURE 2 Hierarchical structure of driving task (Janssen, 1979)

With two below levels in the figure: Maneuvering and Control levels, they are affected partly by environmental inputs such as road environment, weather, roadside objects, distraction from both outside and inside the vehicle, or less tangible environmental impacts such as traffic rules of current places, driving culture, social norms. Therefore, in the context of touchscreen display, the information from this system in the car is a type of environmental input and could partly affect driving task performance in both maneuvering and control levels.

2.1.2 Human information processing capacity

Indeed, human information processing capacity is limited, a person cannot do more than one thing at the same time. Driving task is a complex task requiring hands to maneuver the wheel, feet to press the pedals, eyes to see the road and other peripheral objects and brain to process all the information received. The capacity of information process in general, or specifically driving task is not only about the amount of information receive but also the rate of processing information. If a person receives an amount of information and process it at a slow rate, to compare with another with a faster rate, the person with higher rate needs more capacity of information process. Their cognitive or analysis process performs more intensively and critically than a slow rate of process. And driving task is a temporary task, the drivers would have to identify multiple information from the vehicle and outside environment within limited time and quickly response it. Hence, driving task is considered as a highly intensive task, which requires higher information processing capacity than other permanent tasks. The rate of information process varies relatively with correspond of speed, the higher speed of the vehicle, the rate of processing increases and the greater of information processing requirement. At a certain point, when the demanding of processing goes beyond the limit of capacity, the drivers could witness an overwhelming process , because they might miss information for example: not able to observe a sign on the road, or see a red-light at the intersection, or might not have enough time to process or the rate of processing is extreme such as when the driver is overtaking a car but suddenly another approaching car appearing on the opposite direction, this time the driver can see the approaching car but not enough time to respond such as braking or avoiding. The missing information or missing response is called failure of information process during driving (Shinar, 2017), and it could lead to a crash at the time when needs a critical decision. In the context of using a touchscreen display, the driver performs secondary task on touchscreen display and driving task simultaneously, if the demand of processing both touchscreen and driving task is greater than driver capacity, a failure can happen and lead to a crash if at that time the driver must make a critical response.

A normal person with a good mental health can do one or maybe two complex tasks at the same time, or he/she can do multiple simple tasks simultaneously as long as the information processing capacity to perform these tasks is below the limit of human information process. However, to have a better understand the limit of information processing capacity and how the capacity is distributed into which sectors of information process, is crucial to investigate. Several models of human information process were proposed, and an explanation model from Wickens et al. (2021) is commonly applied in any types of time-dependent tasks. The model is shown in the figure below.

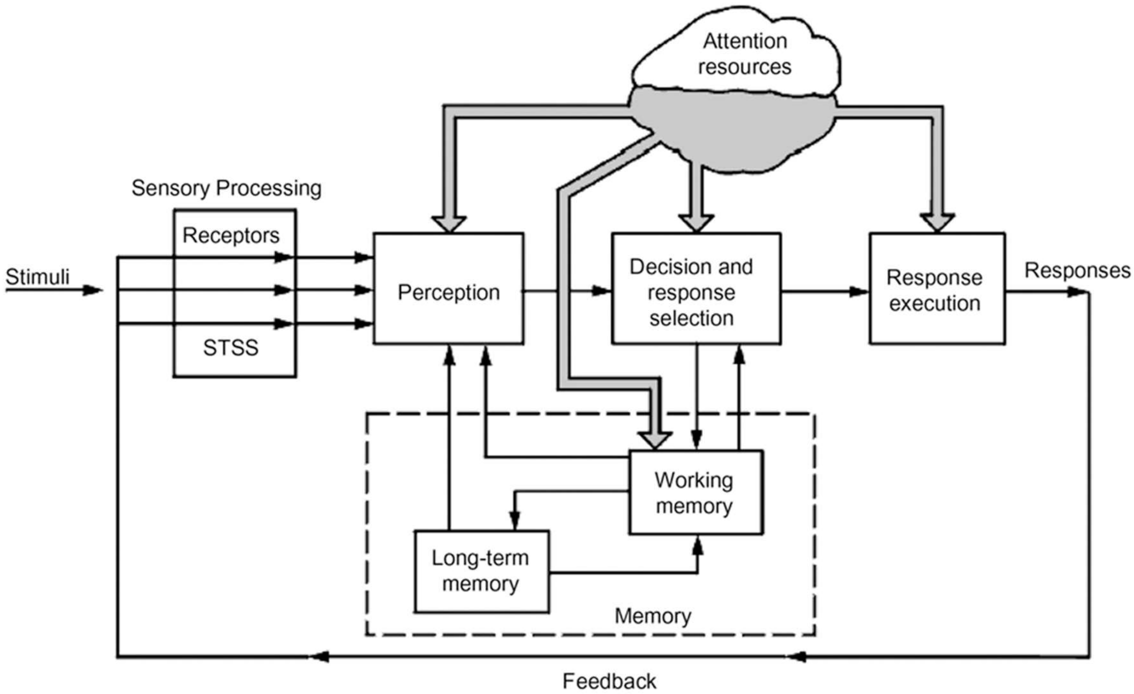


FIGURE 3 General model of information processing distribution (Wickens et al., 2021)

The model can be explained from the left with information of stimuli from the environment are received by sensory receptors such as eyes, ears, skin, noses …, then the received information is scanned and extracted by driver perception. All relevant information now is selected with the help from long-term and working memory, only necessary information is then delivered to decision-making and decision-selecting processor of human. After a decision have been made and selected, a response will be executed physically back to the outside environment. During the whole process, human attention capacity is distributed into each step with different portions. For example, if there are much of coming information to scan and extract, consequently, the attention for this step is extremely high. However, after only relevant information being extract, now the information is narrowed down, and the person only have to process one piece of the beginning input information by smaller amount of attention to compare with the previous step.

With the secondary tasks in a touchscreen display, the above model could be used to explained how the attention capacity of the drivers share to both main driving task and secondary task with touchscreen display. The below figure illustrates the procedure of attention distribution to both tasks.

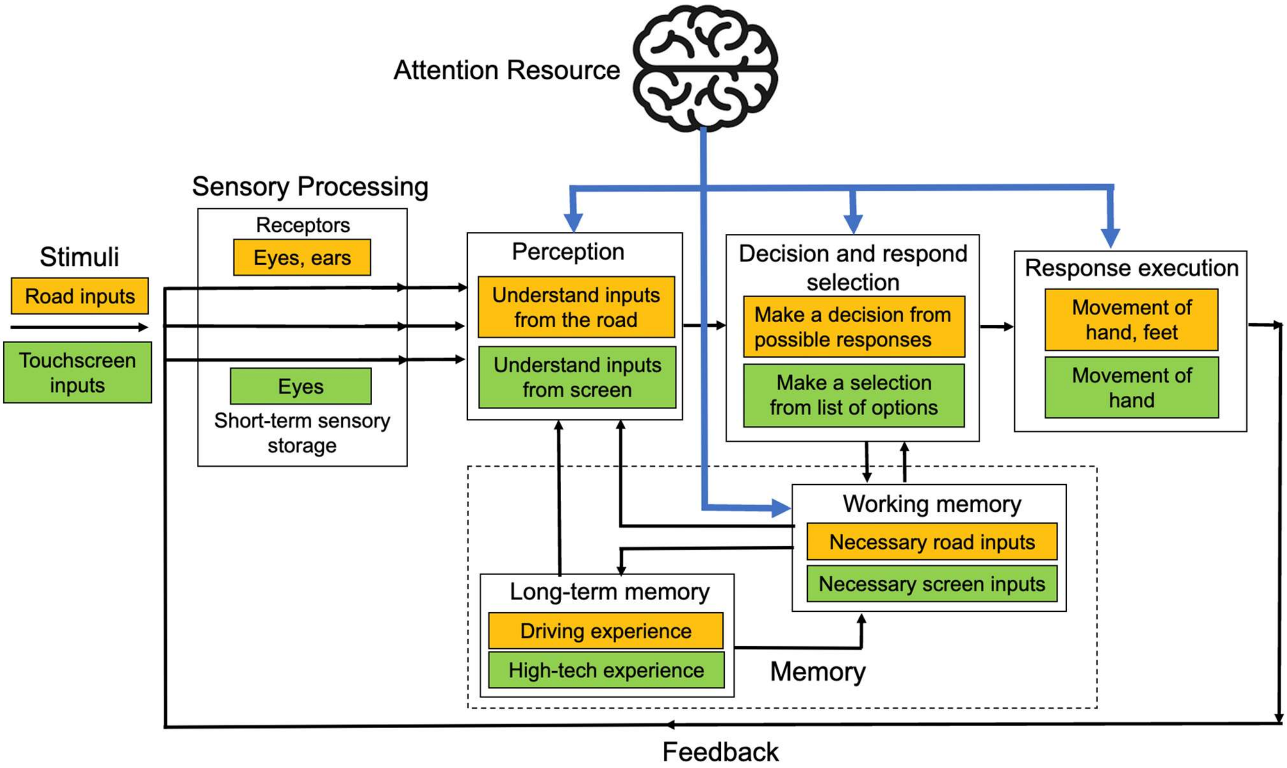


FIGURE 4 Information processing capacity distribution model of driving task and touchscreen task while driving.

As the driving task information process, a secondary task with a touchscreen performed by drivers is through multiple processing steps until a response being made. During each stage of information process, from the beginning stage receiving the stimuli information for the environment to last stage converting into physical actions, the drivers have to share attention resource to both tasks. Since human information resource is limited, the driving is a high-attention and complex task, therefore, a touchscreen task being manipulated during driving could lead the drivers to be task-overloaded and cause risks. In figure 4 shows the two lines of driver attention performance level and environmental demands during driving through the time. The graph illustrates ability of drivers to adapt environmental changes through driving time, however, by the time the driver attention performance decreases because of various reasons (fatigue, sleepiness, secondary tasks…). If there is a sudden and unexpected demand from environment, the sudden demand could overwhelm the driver attention, and potentially cause a crash.

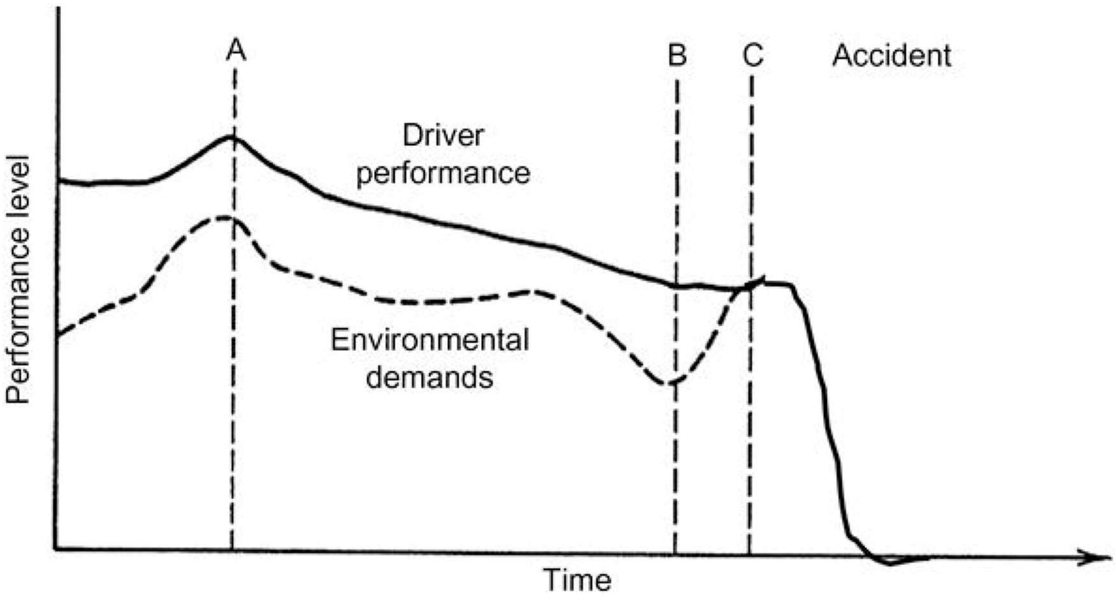


FIGURE 5 Relation between driver attention performance and environmental demands in a period of driving (Blumenthal, 1967)

Todays, with the expanding of touchscreen display in most of modern cars, a variety of new functions have been added, with varied complexity. Hence, the more complex touchscreen tasks are committed, the more information process capacity is occupied, and the more driving performance and safety is impaired.

2.1.3 Attention capacity and distribution of attention

Attention is ranked as one of the most critical components in information processing performance (Klauer et al., 2006). Indeed, it is defined as a source of psychic ability to actively response to any tasks instantly at any time, give the drivers to have enough time to process and react immediately any stimuli from the surrounding environment. Allocation of attention is represented by total amount of attention and distribution of attention to multiple tasks (Shinar, 2017).

Each of people has different capacity of attention, and the amount of attention used for a driving task such as an experienced driver can use less attention intensity for driving task than a novice. Driving is a complementary process that drivers can automatically and unconsciously perform several familiar tasks with less attention demand than novice drivers. They are able to perform driving task with less demanding attention, therefore when committing a secondary task, experienced drivers can focus more on carrying out non-driving tasks without highly at the same time concentrated into main driving task. It gives them less consuming time and higher performance to conduct a secondary task rather than the novice one who is committing two tasks simultaneously within highly intensive attention.

Even though, people can do quite good in task allocation of multiple task performance (Wickens et al., 2021) .However, the distribution of attention is divided unequally between main driving task and secondary task (Shinar, 2017). Mostly the drivers focus on driving task than non-driving tasks, however, there are some moments that they are almost diverted into the secondary tasks, thus the level of attention in driving task is insufficient to maintain the safety and normal performance of the vehicle.

In addition, distribution of attention depends on the amount and rate of information processing demand on these tasks (Shinar, 2017). For example, if a complex secondary task requires a high penetration of cognitive, visual or gesture abilities such as calculating a complex mathematical equation, reading a message, writing or texting a sentence, could lead the driver to focus and employ more attention on the non-driving tasks instead of main driving task. And in case of information processing rate, if the driver has to response extremely quickly to a stimulus from surrounding environment such as a sudden cyclist reaching from left side, then at that moment an instant response has to be decided and executed (stopping or steering the car), the rate of processing information requires the driver's attention to distribute more amount of attention from the driving task to tackle this emergency situation.

Moreover, according to "Theory of multiple resources" Wickens (1984) assumes that distribution of attention depends on three dimensions of human information processing resources which is demanded by the tasks. Particularly, three dimensions consists of the stage of processing, the input modalities and the response modalities. If both two tasks have same component types in information processing, input or response dimensions, these tasks will be more interfered each other than two tasks with different components. For instance, a driver driving the car and opening the radio system by voice recognition is less demanding and safer than opening by touchscreen gesture. Because driving task and using a touchscreen have to share the same resources of driver's visual (looking towards the road and towards the screen) and manual (steering the car wheel and touching the screen) abilities. On the other hand, with difference components in input and response dimensions, driving and using voice recognition is less interfered, because each of the task requires different resource from the drivers. With driving task is using visual and manual resource, however, the secondary task with voice recognition is employing verbal and auditory resource from the driver, these required resource are distributed into only one particular task, not split into two tasks. All human resources have been utilized independently into separated tasks, not interfered each other. Therefore, theoretically tasks with touchscreen display requires more attention resource from the drivers than other types of interaction methods with the vehicle. Hence, carrying out a touchscreen display task while driving could negatively affect driver's attention.

2.2 Distraction impacts from a touchscreen display reviewed from current studies

2.2.1 Distraction impacts from touchscreen display on driver's attention

Distraction is an irrefutable principal factor that poses a significant threat to driving safety; however, all types of distraction affect driver's attention equally or unequally? There are many research concludes that visual distraction is one of the riskiest determinant that causes a considerable impact on driver's attention failure while driving (Shinar, 2017). A secondary task with a touchscreen display does not only create visual distraction but it also causes hand-manual distraction. Thus, the degree of risk when committing a touchscreen task is more intensified in term of safety driving.

To find out the effect of visual-manual distraction from a touchscreen display, most of the research shows the impacts through multiple measurements such as reaction time for responding an unexpected event, steering and speed maintenance, glance behavior (Useful field of view (UFOV), visual acuity, color vision, motion detection, eye movement…), performance in secondary task (task completion time, perception and frequency in performing task…) or crash analysis (crash rate and distraction types relation…), from a variety of study methods (simulation study, naturalistic driving by instrumented vehicles or recorded video in participant vehicles) in different environment (in laboratory, closed and open road). Or from a subjective survey or interview after a crash or a driving test, the researcher could investigate the participant's perception of performing a secondary task while driving could impair their attention or not, and maybe investigate the causes of these distractions.

As we already mentioned above about difference impacts of a touchscreen on driver's attention based on the touchscreen task complexity (time to complete, amount and rate of information process). In this section, a brief literature review of current studies about touchscreen impacts will be represented from the most complex tasks to the simplest with the touchscreen display in the vehicle. Because of dramatically increasing in number of secondary tasks, only the commonest and most basic tasks will be studies.

2.2.1.1 Navigation tasks

Navigation task is considered one of the most complex and long-occupied tasks in the vehicle (Shinar, 2017). Significant of research have showed impairment of driver's attention when conducting a navigational-related task. A navigational task consists of multiple sub-tasks such as entering the destination, choosing the most convenient route, and constantly tracking the route by looking at the screen and multiple gestures (zooming, panning, scrolling ...).

In a simulation study about glance analysis of drivers reported that both length of single glance, total glances, and the numbers of glances per several sub-tasks (finding the name of road and estimate the shortest distance to a near destination) are significantly higher than a normal driving tasks (Dingus et al., 1989). Particularly on sub-tests of touchscreen, another simulation study investigated text-entry (typing address of destination) and category search (scrolling kinetically and selecting a specific place from a list of points of interest) were the most visual demanding sub-tasks. Both two sub-tasks had the highest maximum in-car glance duration per each task (2.7s and 2.5s), and these glance durations are above the criterion: duration of a glance away from looking ahead for a non-driving task should be under two seconds from the guideline of (National Highway Traffic Safety Administration, 2013). Moreover, other visual parameters: Total glance duration per sub-task, number of glances per sub-task and means of single glance indicated significantly higher than other sub-tasks (Kujala et al., 2013). In additional, if the total glance duration per task is long enough, it could lead a failure in peripheral and mirror scans and pose an inaccurate perception of current traffic situation (Dingus et al., 1989).

Another simulator study was conducted by researchers from Michigan University, USA (Tsimhoni et al., 2004) to compare three types of input methods of entering addresses in a navigational system in the vehicles: word-based, character-based and touchscreen keyboard-based. After the experiment with 24 participants, not surprisingly the touchscreen keyboard entry took longer time (86s) to complete the task than both speed recognition (15s and 41s).

In 2020, IAM RoadSmart compared two most common types of operation system in vehicles: Apple CarPlay and Android Auto when drivers communicated by voice and touch gesture. The study showed that navigation task with a touchscreen was one of the most demanding tasks besides reading and calling tasks with about 20 seconds per task compared with voice recognition only 4 seconds.

With other moderating factors such as curvature road and gender, the total task time and total glance duration, number of glances and number between glances were even relatively substantially increase. It is simply explained because in the high-demanding road events, the drivers realized needing more visual, cognitive and manual resources to the main task, therefore the secondary task witnessed a degradation. Even though, human is quite good at attention allocation, however, if they maximize the use of attention resource for both main and secondary tasks, a failure could be happened with an expected event.

2.2.1.2 Listen to music

According to a survey study from America and a small-scale survey as a part of my internship conducted last year, listening to the music is assumed as one of the most common tasks with the touchscreen as well as an infotainment system in the cars, only behind navigation task(Do, 2021; IHS AUTOMOTIVE, 2016). Therefore, it is crucial to investigate the effects of touchscreen on the music task.

As a subtask of navigational task- selecting a point of interest, in a music selection task, most of hand-gestures performed with the touchscreen are to scroll the list of music, to type the name of a song or a singer (short text input) then to select a wanted song, album, single or types of music. However, the length of music list is significant longer than a list of point of interest, could reach to hundred songs. The longer length of the list associates with a longer glance time and higher number of over 2-second glances per task, the more information processing resource to use, and the more used hand-gesture resource to scroll, hence the higher demanding visual for browsing music task and less visual-manual attention for driving task (Lasch & Kujala, 2012; Lee et al., 2012).

Additional, performances of selection task within a long list of songs showed that target accuracy with a direct touch was less than using an onscreen buttons or pressure buttons (Ng & Brewster, 2017). Failure in choosing a music artist from a list was also appeared more than pressed buttons when using touchscreen with kinetic (35% participants) and swipe (11% participants) scrolling methods (Lasch & Kujala, 2012). Since errors are occurred more due to lower selection accuracy by direct touch, it could increase task completion time for choosing again the desired song and annoy the drivers from driving task.

Nevertheless, song picking time within touchscreen display was twice and three times quicker than an onscreen and pressure-based buttons, therefore, a trade-off between the selection accuracy and time is happened. On the post survey of the study, participants liked the direct touchscreen selection the most, they perceived as easiest method to select a particular song.

Another study also confirmed that the drivers could be able to find a song quicker via a touchscreen display than a physical system. However, they had to spend more time off-road with prolonged time per glance and number of glances as well (Garay-Vega et al., 2010).

2.2.1.3 Dialing

Making a phone call is considered as one of the most common tasks besides texting when the drivers want to communicate with others while driving. While making a phone call in the vehicle is mostly prohibited during driving, however, there is no traffic law that preventing to make a phone call via in-vehicle infotainment system mounted on the dashboard. Although there were numerous articles about making a phone call by cell phone, experiments on an infotainment system particularly on a touchscreen display is limited. However, several studies about hand-free cell phone or similar characteristics could be considered as a source of literature to review.

A study conducted with participants of 36 drivers when they are dialing by a flip-phone with physical buttons and by a touchscreen mobile phone. Even though cell phone is a handhold device not as a hand-free device as a touchscreen display. However, because of the similarity in holding two phone types, therefore, this study focused more on difference in tactile response that a physical button system could provide to the drivers, but a touchscreen cannot. According to eye-tracking analysis data, participants using a flip-phone with physical buttons performed the tasks with a safer manner with more time looking on the road because of less glances to the phone than a touchscreen. And they also finished the task faster compared to touchscreen users. In addition, the number of glances longer than 1.6s when deploying a touchscreen was 2.1 times higher than flip-phone(Reimer et al., 2014).

To compare attentional load between infotainment tasks and dialing task, another naturalistic study, 120 drivers were participated in and allocated in different car brands. During driving in a low-traffic residential road with 2 miles length, the drivers performed several secondary tasks with three types of in-vehicle systems (Strayer et al., 2019). The results reveal that calling and texting was slightly less cognitive and visual demand than navigation and audio entertainment tasks. In addition, committed time to finish the dialing task was significantly shorter than that of navigation and audio tasks. Therefore, the visual-cognitive distraction when dialing a number is less visual-cognitive intensive than other tasks.

2.2.1.4 Select a phone contact from the list

In a detailed study about the effects on driver attention of using a touchscreen to call a phone contact. Selecting a phone number in the contact list by voice-based interface took less time than using a touchscreen manual interface. However, with a more complex phone selection task such as select the home number of a person if he/she has both mobile and home numbers, task time using voice-recognition was more time-consumed than a touchscreen (Mehler et al., 2016).

Mean duration of off-road glances and total eye-off road time when calling by touch-based screen was higher than that of voice-based system. Only under 1.4 percent of participants glanced more than 2 seconds, in particularly, only 0.5 percent of voice-based interface users took longer glances than 2 seconds while touchscreen user was 2.9 percent (Mehler et al., 2016).

Another research also assessed calling and radio task using physical button interface to check whether these tasks are safe in accordance with NHTSA guidelines or not. Even average duration of each glance was under than 2 seconds, however total duration of off-road glances was higher than 20s (NHTSA guideline). Therefore, calling task was failed to accept as a safety task when compared with NHTSA guidelines.

To compare with other secondary tasks, time consumption of a calling task was less time than navigation, texting tasks, however, it was higher than time of entertainment tasks (Strayer et al., 2019).

2.2.1.5 Radio channel adjustment task

Besides other tasks, radio listening is also a common task that almost the cars have been equipped as a default function that could provide auditory information to the drivers. And from the crash data, tuning radio is assumed as one of the major causes led to distracted crashes. Therefore, tuning the radio by a touchscreen should be reviewed in the study.

With a brief review of current literature, adjustment of radio station during driving was not considered as distracted as the other secondary task. Indeed, in a glance analysis study which observed the eye-behavior of drivers between changing the radio station and two others safety tasks: looking at rear mirror and odometer. During 22 miles driving road, only two of 113 off-road glances exceeded than 1.6s. Even the longest duration glances were for the radio task, and not as other safety tasks only required single glance, in radio task drivers looked more than one. However, general eye-glance data of both radio and rear-mirror was quite similar. Hence, radio adjustment is considered as visual demanding as looking in the rear-mirror (Sodhi et al., 2002).

Another comparison with climate task showed that during the radio tuning task the drivers looked the touchscreen 2.7 times while with climate task only 1.4 times on average (Zwahlen et al., 1988). In addition, when compares with cassette task and dialing on cell phone, glance average in changing radio channel was the longest with 1.02s per glance. However, the percentage of longest glances appeared in telephone task instead of radio task, and the drivers spent 53% of total task time to look at the cell phone while that of radio task was only 26%. Therefore, even the average of glance at radio tuning was highest among tasks, but it is still less visual demanding than dialing task (Wikman et al., 1998). Nevertheless, the environment also mediated the time proportion of off-road looking, the drivers took longer time to finish the task on highway than urban way. Because the drivers quickly performed the radio task, so during the task they spent more percentage of time to look at the display than on a highway.

2.2.2 Distraction impacts from touchscreen display on driving performance of drivers

The distraction caused from employing a touchscreen display is classified as visual-manual distraction which was verified that significantly diminishes driver's ability to control the car (Bao et al., 2015). Since driving task is a vision-intensive and manual task required drivers simultaneously looking ahead (visual requirement) and maneuvering (manual requirement) to drive the vehicle safely. Therefore, visual and manual attention capacity of drivers have been distributed partially from main task to a secondary task with a touchscreen display. If the secondary task is complex and time-consuming, the main-driving task could experience a failure because of lack of response from drivers, and the failure could lead to a crash.

The section above already provided attentional impairment of drivers by eye-tracking analysis and task completion indicators from different studies. In this section, multiple measures of driving performance will be discussed to reveal negative impacts of the touchscreen display. Likely the above part, the most complex and time-intensive secondary tasks with a touchscreen display such as navigation, song and radio selection, dialing alter driving performance the most.

2.2.2.1 Navigation

An on-road empirical study was conducted with thirty-six participants from 18-35 years old. The researcher in the study focused on information analysis from both commercial car and truck drivers when they interpreted navigational information on the display (Blanco et al., 2006a). While there were only few unplanned lane deviations from the light-vehicles, on the other side, with truck drivers there were significant reductions in precision of the truck indicated by larger speed variation, longer minimum headway, large headway variation and increase in number of lane deviations. However, in this study the participants interpreted with the display by glances without touching the display. Therefore, we can firstly conclude that without manual distraction, the driver could perform equitably to compare with baseline of driving.

In another study conducted on a simulator in Michigan University which already mentioned above, when comparing two other types of voice input methods to search a particular address from three navigation systems (Tsimhoni et al., 2004). Impairment in driving task performance of typing the address via a touchscreen display compared to other methods was shown by multiple measures. Degradation in vehicle control was resulted by 60% higher than others in standard deviation of lateral position, as well as in 0.12 degree larger of steering angle standard deviation than normal driving. Reduction was also shown in forward velocity when compared with no task, the following distance with ahead vehicle was longest (167m) when searching address by touchscreen.

The negative impacts of a touchscreen were also presented in changing lane test performance which was tested in another simulation study. When drivers had to find a Point of Interest and search an address, simultaneously they maneuvered the steering wheel to change the lane. The results reveal that deviation in change lane path exceeded the baseline, and the drivers took longer time to initiate the lane changing than without secondary task (Harbluk et al., 2007). In addition, when searching a Point of Interest, the drivers endured significantly higher percentage of speeding errors and lane excursions than physical buttons (Kujala & Saariluoma, 2011).

2.2.2.2 Listen to music

There has been several research investigated about the effects of deploying touchscreen display to search and play the music inside the car. In 2012, a simulation study was conducted to evaluate the different types of input gesture methods to search and play a song when utilizing a touchscreen display (Lasch & Kujala, 2012). The searchers found a significant reduction in car average speed compared to no task condition (52 km/h vs 54 km/h). However, no evidence was detected in lane excursion or speed violation. Research from Garay-Vega et al. (2010) has the same result with no difference in driving performance when selecting a song from an in-vehicle music retrieval system.

Similarly, in another article also concluded that there is no significant degradation in performing main task when committing a touchscreen display to find a song in a short playlist. Nevertheless, with a longer playlist the drivers have to take longer time to find the song, hence greater variability of speed and lane maintenance was suffered by drivers (Lee et al., 2012). Similarly, interaction with a fixed-iPod in vehicle as another version of music task with a touchscreen display was investigated, and lateral speed and lane position variability was substantially increased compared to no task (Crisler et al., 2008).

2.2.2.3 Dialing

A simulation study was conducted to assess effects of touchscreen and voice responses on car following test performance of drivers when carrying out a secondary task which required participants to call out numbers in ascending order by tapping the touchscreen. The results showed that secondary tasks with the touchscreen significantly affected the driving performance with decline in speed average and escalation in headway distance and lateral position compared to that of voice feedback from drivers (Hagiwara et al., 2013).

Effects on driving performance was also conducted when researchers compared two different interfaces, manual-dialing via a touchscreen and voice-dialing via a voice-recognition system by a computational model and a simulation study. Both approaches concluded that full-manual dialing yields the larger in lateral position deviations and speed deviations than voice-dialing and no task (Salvucci, 2001). Another study also showed a tendency of drivers in a lower variability of lane keeping when dialing by a physical button phone compared to a touchscreen phone (Reimer et al., 2014).

2.2.2.4 Select a phone contact from the list

A simulation study compared vehicle control performance between touchscreen, voice base system and baseline reveal that in general drivers tended to be reduced their speed when committed phone call task. There was a significant reduction in speed of touchscreen users compared with voice phone calling. However, no significant difference in reduction of standard deviation of speed between two systems. Relative increase of steering wheel reversal with touchscreen users (35.2%) is higher than voice-based calling (28.6%) (Mehler et al., 2016), however the difference was not significant.

2.2.2.5 Radio channel adjustment task

A closed-track experiment was conducted to find the relationship between number of glances and lane keeping during performing radio task. From the lane tracking data, in an ideal condition on a 3.66m width lane the drivers has 3% change of lane encroachment, and the probability increases to 15% if on 3.05m width lane (Zwahlen et al., 1988).

In a more detailed driving performance study, a comparison between phone conversation, tuning the radio task and baseline of driving without distracter was carried out in a simulation experiment. After data analysis, the driving performance from the radio task was the worst with significant lower speed maintenance and the highest speed deviation from posted speed limit (Horberry et al., 2006). The performance was even downgraded with the elderly people group.

2.2.3 Distraction impacts from touchscreen display on driver workload

Self-report or questionnaire are the most direct way to assess the driver's perception about the workload as well as distraction of the secondary task. Because of complexity and multi-dimensional concept of driving distraction and workload, NASA Task Load Index is developed and applied mostly in driving studies for measuring and conducting a subjective mental and physical workload assessment. The tool consists of six assessment dimensions: Mental demands, physical demands, temporal demands, efforts, frustration level, and performance when participants perform any tasks. Each dimension is weighted by 10 points liker-scale measurement from very low to very high. In the past, subjective measurement by NASA TLX tool has been used to assess driver's perception of many secondary task after simulation test. In this part, subjective measures from drivers will be reviewed to briefly understand about driver's perception when performing the secondary tasks.

2.2.3.1 Navigation system

Based on a recent NASA TLX assessment in simulation research, the navigation system was perceived as highly mental demanding and effortful task. Frustration and physical demand had the lowest point which implies that the navigation task does not required much manual and attention capacity from the drivers (Yared & Patterson, 2020). However, to compare with different interfaces such as auditory navigation system or visual-auditory navigation system, all aspects of workload from a touchscreen display were significant higher (Harms & Patten, 2003).

Particularly, in the navigation task with a touchscreen, after the experiment participants generally assumed that except searching a favorite place, searching a particular place by typing and finding a point of interest were significantly workload demanding than only driving (Kujala et al., 2013).

In term of gesture interaction types when performing navigation tasks, most people responded that flicking gesture is necessary to use in the navigation task and more convenient because of familiarity with touchscreen in cell phone. However, pinching gesture (zoom-in and out) was considered not appropriate to perform the task while driving, because it required higher visual attention workload than others. Nevertheless, all gesture methods did not create difficulties for the drivers except tapping gesture (Kim & Song, 2014).

2.2.3.2 Listen to music

In general, when performing the music player tasks via a touchscreen there is a subjective assumption from all drivers that level of workload is higher than baseline without secondary tasks (Mitsopoulos-Rubens et al., 2011). The participants again recalled for voice-interface as for a safer interaction because the subjective measures revealed that there was no significant difference between workload scores of voice-control and driving task. For each workload dimension (frustration, perceived effort and performance), there were significant different in each layout concept of presenting list of music songs (Jeon et al., 2009).

With driver's perception in music selection methods, most of participants agreed that kinetic scrolling is the most demanding, distracting, difficult to use and least preferred than physical buttons and swipe methods. And buttons was the best choice to find and select because it is easy to use, least distracting (Kujala, 2013; Lasch & Kujala, 2012).

2.2.3.3 Dialing task

A subjective measure comparison between dialing and calling task and other secondary tasks was conducted, and cognitive and subjective demands when drivers dialing and calling are lower than navigation, entertainment and texting tasks (Strayer et al., 2019). In general, dialing via an infotainment system in the vehicle from user perspective was considered as not demanding as below the high workload benchmark.

2.2.3.4 Select a phone contact

After a simulation study, a self-reported workload test was recorded with majority of participants assumed that using a touchscreen display to select a phone contact is more workload challenging than employing a voice-based system (Mehler et al., 2016).

Another subjective workload study concluded that calling a phone number on the list is slightly less cognitive demanding than entertainment and texting task. And the demand for calling is under the high workload benchmark, hence majority of respondents perceived that calling is the easiest task (Strayer et al., 2019).

2.2.3.5 Radio channel adjustment task

Overall subjective workload scores from NASA-TLX survey in radio task showed that the participants perceived significant increase in workload when adjusting radio channels and bass/treble balance. The increase in workload also escalates relatively in more complex road environment and tasks (Horberry et al., 2006).

In addition, when driving manual-distraction caused by radio tasks likely other secondary task was subjectively believed as significant higher workload than interacting with voice-recognition system (Medenica & Kun, 2007).

2.3 Summary and Problem statement

2.3.1 Summary of Literature Review

Firstly, driving task is a main and critical task which consists of three levels of decision-making process: Strategic level, Maneuvering level and Control level. Each level consumes driver different amount of attention capacity and time to process. Therefore, any secondary tasks not related to driving task is considered as a source of distraction. Based on model of information processing distribution, secondary task with an in-vehicle touchscreen display includes multiple processing steps. Because when drivers perform the touchscreen task, from different types of stimuli received the drivers have to process and give responses constantly. Due to limitation of human information processing capacity, a touchscreen task could lead to information over-load and cause risks on the road. In addition, a touchscreen task requires manual-visual attention which is simultaneously distributed to driving task. Consequently, overload of manual-visual capacity is potentially happened. Hence, the secondary task with a touchscreen display in the vehicle is assumed as the most risky task in-vehicle compared with other secondary tasks with different types of human-machine interfaces in vehicles.

Secondary tasks with a touchscreen display consist of a variety of functional tasks from complex tasks such as configure the navigation and sending messages, to simple tasks such as climate adjustment and radio station change. The more complex task, the more information processing capacity distributed, the more distracted and the more attentional impairment. Most research studied about distraction impacts of technology devices in the vehicle usually assess driver's cognitive and driving performance aspects. For driver's cognitive impacts, mostly attention capability is assessed by measuring glance behavior or reaction capacity of unexpected stimuli. Or for driving performance impacts, lane change, lateral and longitudinal maintenance, speed and other variables are measured and evaluated.

From perspective of cognitive impacts, driver's attention capability is varied based on complexity of the tasks. With navigation task is the most distracted task, time-consumed indicated by deterioration of length of glances, number of glances and task duration. Music selection is assumed less intensive than navigation task, however, the number of songs in the list relatively affects the visual attention of drivers. Dialing task in the vehicle is considered less cognitive and visual demanding than navigation and entertainment tasks. Tuning the radio channel task was recorded as less visually demanding than a dialing task. To sum up, a secondary task always distracts the drivers, but the degree of distraction is based on a lot of aspects such as driver, road, task complexity and traffic situation.

Secondary tasks with a touchscreen display in general downgrade driving performance of drivers. The level of driving degradation witnesses a relative increase depended on task consumed rime and visual-manual effort to carry out the tasks. As cognitive impacts of the touchscreen, navigation tasks worsen driving control the most indicated by impairments of lateral and longitudinal, speed maintenance measures (Blanco et al., 2006b; Kujala, 2013; Tsimhoni et al., 2004). There was limited evidence to state that music selection lessens driving control ability, only speed reduction and lane maintenance were slightly affected. Similarly with a dialing task by a touchscreen, only significant differences among touchscreen and button manual-dialing, voice-dialing were found, however the missing piece between dialing task and baseline is needed to figure out. Radio channel adjustment task is also lack of significant control performance deterioration to compared to the driving task.

In term of subjective workload assessment, most of collected subjective data assume that navigation, entertainment and texting task are considered as source of cognitive and visual demand when compared with voice-recognition system and the baseline. Dialing task is evaluated as not much demanding to these other secondary tasks (Strayer et al., 2019).

2.3.2 Problem statement

According to the reviewed studies, references about distraction impacts of in-vehicle touchscreen on driver attention and driving performance are limited and not updated. Most of in-vehicle technology device research were to study about the impacts of mobile phone and traditional infotainment system with physical buttons. In addition, majority of studies focused on comparison between different interference systems such as voice-recognition, physical buttons, trackpad or controller stick, or in more detail assessment about different types of input method such as scrolling, swipe, direct touch or press-based touch, or to study about effects of variety of layout presented in the touchscreen display. However, there is a lack of studies to evaluate magnitude of distraction effects on drivers compared to baseline.

In additions, new safety enhancement functionalities (Advanced Driving Assistance System, Passive Safety System, etc.) have been recently and widely developed and integrated into a touchscreen display which helps the drivers to activate and utilize these features quickly throughout the display. Hence, a secondary task when drivers activate or deactivate one feature of safety system in the vehicle should be included in this study.

Therefore, with respects of all problem above, a new study concisely examined about distraction impacts of an in-vehicle touchscreen on driver attention and driving performance, and compared with normal driving task is essential.

2.4 Research questions and objectives of study

Research questions are formulated as below:

What is the effect of the use of touchscreen while driving on workload and driving performance of drivers?

Sub-questions:

- What is the performance of drivers on the touchscreen tasks when they are driving?
- Which is the most touchscreen-related demanding tasks for drivers while driving?
- Is driving performance in general degraded while performing touchscreen tasks?
- Do driver's demographic background (gender, age, driving experience and frequency, in-vehicle infotainment system experience and frequency, etc.) influence driving behavior during interacting with a touchscreen?
- Which subjective determinants of driver's perception about the touchscreen system could influence driving performance while using a touchscreen?
- How demanding do drivers perceive touchscreen task while driving from NASA-TLX ?

Objectives of this study is to explore safety aspects of using a touchscreen infotainment system. To evaluate the safety of the touchscreen, this study will be conducted by assessing perceived demands and impacts of touchscreen on driver's driving performance. Through a driving simulation study, multiple measures of driving performance which are objective measures will be recorded and analyzed. Driver's perception about touchscreen display and workload when using a touchscreen system are two subjective measures to evaluate touchscreen distraction via survey.

The study could help to solve multiple problems related to development of a touchscreen infotainment system from ensuring safety to satisfaction of users. To ensure the safety of a touchscreen, the manufactures and law makers both assess the safety of system through customer perspective and their performance of safety such as by customer surveys and driving experiments.

3 METHOD

3.1 Framework of method

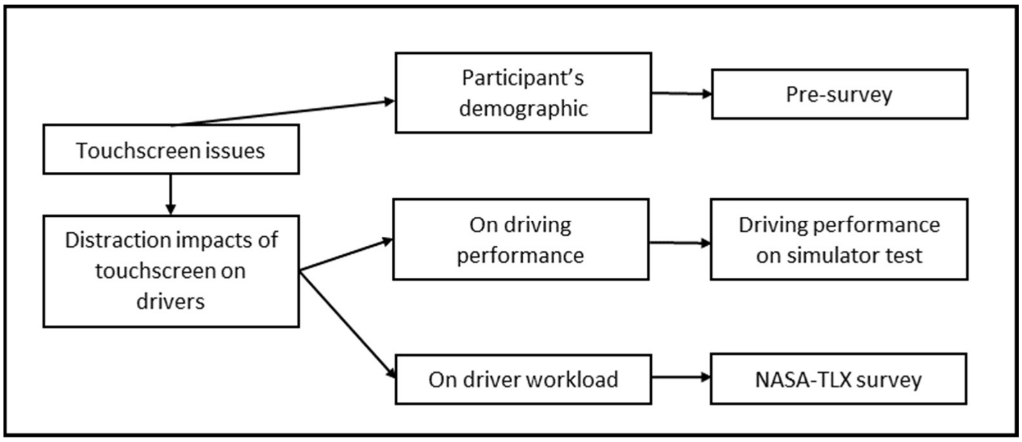


FIGURE 6 Framework of method

3.2 Participants

To recruit drivers for the test, an invitation was distributed via email, social media platforms and direct conversation with participants in two weeks. The candidates were asked to fill in a registration form with basic demographical information such as gender, age, driving license, driving experience and contact. Participants who achieved a driving license type B are eligible. The list of participants was filtered and ensured diversity of participant sample based on their gender, age, driving experiment.

Thirty-six participants with variety of nationalities, driving experiences, gender and age ranges were selected and joined the simulation experiment at laboratory room in IMOB, Campus Diepenbeek, Uhasselt. For each participant, the experiment took about one and a quarter hour to complete including introduction about the study, filling in consent form and pre-survey, training driving, real test and the NASA-TLX. The test was organized in total nine days in two weeks.

3.3 Apparatus

A driving simulation in this study is the most feasible and practical based on scale and requirements of the research. Indeed, a simulator could provide participants the best visualization of road environment in a laboratory. The drivers could experience critical driving situations without any safety or ethical concern. And simulation study is a cheaper and more saved-time method to collect enough data than other approaches (Shinar, 2017). Specially, with a new highly technology devices like a touchscreen which is only available in modern cars, therefore, a touchscreen display integrated with the simulator is applicable to evaluate. Many research which already reviewed above were also applied this approach to evaluate the in-vehicle infotainment system. Therefore, a simulator experiment study is the most suitable and reliable method to achieve the outcome in this study.

3.3.1 Simulator

The fixed-based driving simulator from Transportation Science Institution in Hasselt University was used in this experimental study. The simulator consists of three 40 inches displays which visualize ahead driving scene of the cars within 150 degrees in horizontal, 30 degrees in vertical vision and refresh rate of 30. The displays provide drivers car speedometer, rear and two sides mirrors. With the driving control system in the simulator which helps the participants have the most realistic experience in driving, a four-seat Peugeot car compartment was employed to the study. The driving system includes a steering wheel, an accelerator, a braking pedal, dashboard of the car and a seat. Because this simulated car is a electric car, there is no need to use gearshift in this case, the drivers only press the accelerator to change the speed. The figure below illustrates the simulator of the study.

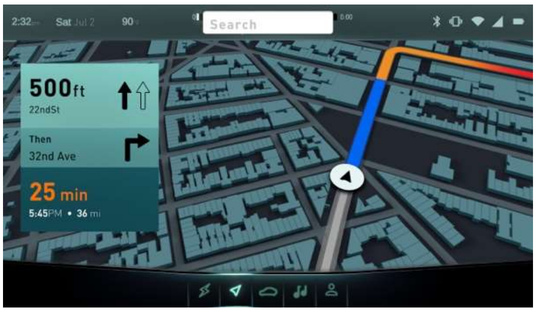
FIGURE 7 Driving simulator of the study.

3.3.2 Touchscreen

According to the study purpose, a full touchscreen without any voice or haptic sensory feedback was employed in the simulator. The touchscreen display is a 10-inch LCD Samsung tablet with high solution and being attached horizontally in the middle of the dashboard. The size and position of the touchscreen are attempted to replicate likely as new modern electric vehicles today such as Tesla which also contains a large LCD touchscreen with high resolution in the middle of the dashboard.

The touchscreen operation system of this simulator was designed based on the touchscreen system of electric vehicle models which contains new features such as battery information or safety system. Therefore, secondary tasks of an electric vehicle had been added to the list of secondary tasks in the study. There are five tabs in the touchscreen operation system, and each tab is categorized as its owned specific functionality such as battery information, navigation, vehicle controlling, radio and music, and communication section. The drivers can easily change the tabs by a tab bar option in the bottom of touchscreen. Table 1 describes five tabs in the touchscreen operation system which were designed in this study.

TABLE 1 List of functionality sections of the touchscreen operation system.

	Tab	Screen interface	Description
1	**Battery information.**		**This section provides drivers information about battery and trip status such as distance, duration, energy usage.**
2	**Map and navigations**		**Map and navigation section helps drivers to locate and instruct to specific places with detail steps and a intuitive map.**
3	**Vehicle controls.**		**Drivers can adjust and activate multiple vehicle systems through this section from engine, suspension, doors to safety system.**

<table>
<tr><td>4</td><td>Radio and music.</td><td>
</td><td>In this section, the drivers can both play the music or change the radio channels by touching and scrolling the list of music songs.</td></tr>
<tr><td>5</td><td>Communication.</td><td>
</td><td>Detail of each contact will be shown in this section. The drivers can scroll the contact list, select and make a phone call.</td></tr>
</table>

3.4 Driving scenario

In this study, the main objective is to figure out how the touchscreen affects driver attention and driving performance. There are two driving tests: a driving test when not using the touchscreen and when using the touchscreen.

The two different tests have the same road scenario to ensure that driving environment not influence the results. However, to mitigate the learning effect that drivers in the second drive can learn from the first drive, the starting points to drive in two tests are different. With the driving test when not using the touchscreen, drivers begin at a highway section, and the remaining test within a touchscreen, the drivers start at an urban segment. Order of the two rides was counterbalanced across subjects with odd ID number participants started driving scenario without secondary task first and even ID number participants started driving scenario with secondary tasks.

To ensure collecting enough data, length of the driving road in each test is equally 14 km which different types of roads and speed limits. Highway and urban way in Europe countries were simulated in the tests with two speed limits on highway (Zone 120 and Zone 90) and two urban zone (Zone 70 and Zone 50). The speed limit signs were posted on the roadside in the beginning of each segment. For each test, it took about 18 minutes to finish the test.

3.4.1 Driving scenario without secondary task

In the test without using the touchscreen, drivers start on a segment of highway with a speed limit of 120 km/h and 90 km/h. During driving on the highway, there were two preceding cars ran parallel with the same speed, the drivers themselves cognitively perceive to keep safety distance and speed with the preceding cars. After the highway segment, the drivers continue to drive on an urban segment. Attention of drivers is measured by two risky situations that a pedestrian suddenly passing, and the drivers must keep their speed below posted speeds with high attention to detect and stop the car before hitting the pedestrian. After driving 14 km, the test will be automatically stopped, and the participants finish their test. The figure below explains the scenario of driving without secondary task with intuitive illustrations.

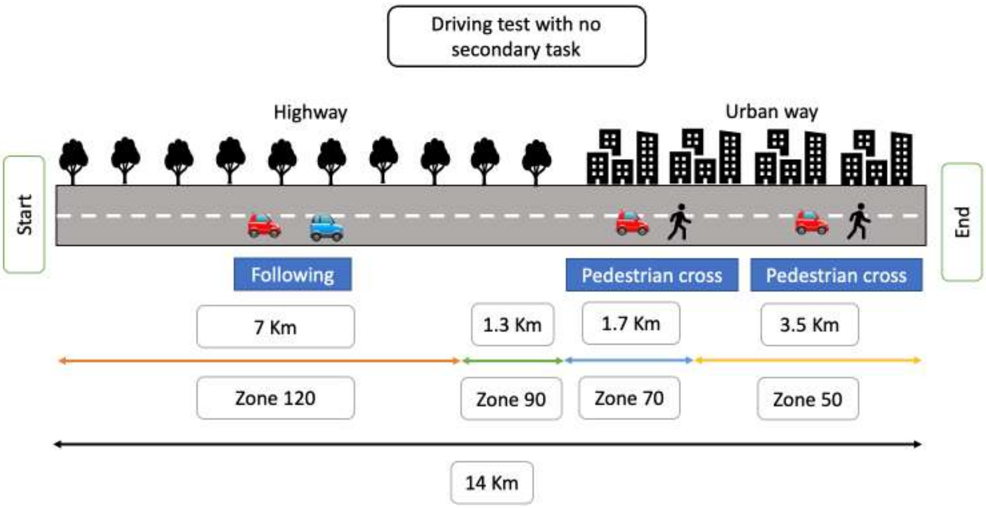


FIGURE 8 Road setting in driving test without secondary task.

3.4.2 Driving scenario with secondary tasks

In driving scenario with secondary tasks, the setting environment is the same as without secondary tasks. However, due to mitigation of learning effects from the previous driving test, in driving scenario with secondary tasks the starting point was moved to urban way, therefore order of events such as car-following and crossing pedestrian were changed accordingly. Then the driver might not realize the two road environments similar and predict what happen next. During the driving, an instruction voice was automatically played to inform the drivers to perform the secondary tasks. When the participants start to drive on the urban road setting, after a few minutes of drive, there was a sound request to search how many remaining minutes to drive with this car in the touchscreen. The secondary task is accepted as success if the drivers can read the remaining minutes to the experiment instructor correctly. While performing the secondary task with a touchscreen, a pedestrian was programmed to suddenly cross the street without zebra line. The drivers at this moment must be careful and conscious on the heading road while doing the touchscreen task to detect the pedestrian and stop. There were total eight touchscreen tasks being performed by drivers. The infographic below illustrates the road setting, driving tasks and secondary task that the participants have to perform in this.

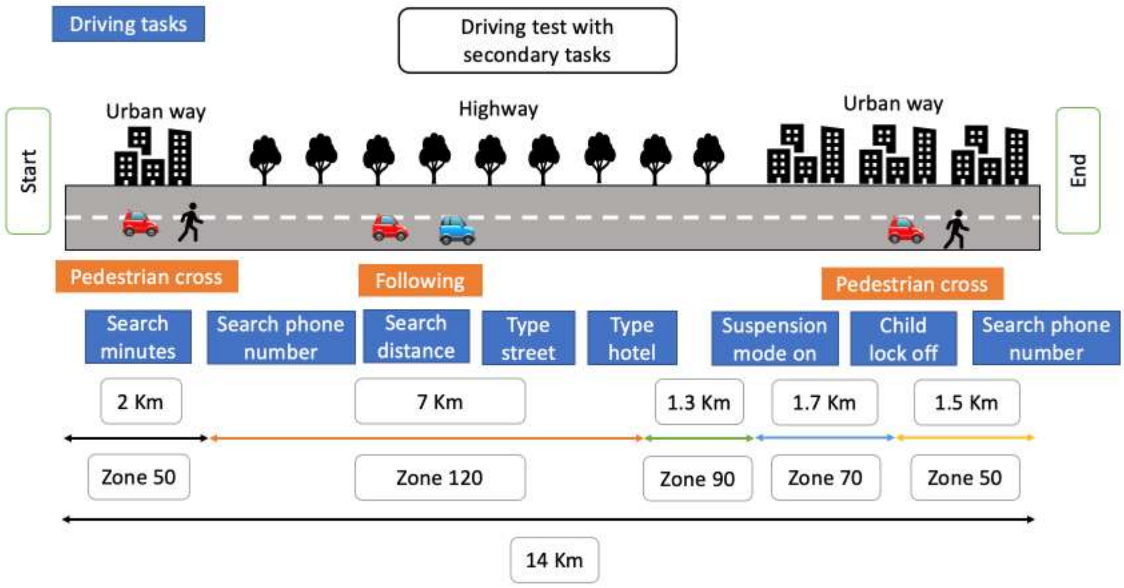


FIGURE 9 Road and secondary tasks in driving test within using a touchscreen.

3.5 Primary and secondary tasks

3.5.1 Primary task

Our main objective of this study is to evaluate the distraction impacts of touchscreen on driver attention and driving performance compared to the baseline driving. Therefore, in this simulator study, primary task is to drive the car as normal drive in real-life. The participants were required to perform their drive as usual. In addition, during driving on the road several additional driving tasks that implies the drivers to ensure the safety such as keeping the distance with preceding cars and stopping when a pedestrian suddenly crossing the street without zebra line. These additional tasks could demonstrate driver's attention and driving performance besides basic measures such as speed, acceleration, steering angle, etc.

3.5.2 Secondary tasks

In the secondary tasks with a touchscreen display, participants were asked to perform several infotainment tasks while doing the primary task. There was an instruction voice played to ask the drivers to perform the tasks during the test. In the driving without touchscreen task, the drivers had to perform eight tasks. The drivers carried out two tasks before critical events (stop at crossing pedestrian) or two in high conspicuous tasks (car-following) or four in normal driving tasks.

The secondary tasks have various of difficulty levels from complex to simple tasks (see

TABLE 2). And the list of tasks was comprised from the most-used features of in-vehicle infotainment system. In each section of touchscreen system, one or two secondary tasks were derived into the list of secondary tasks to ensure the diversity and complexity of touchscreen tasks.

TABLE 2 List of secondary tasks with the touchscreen.

	Tab	Difficulty	Secondary task.	Correct answers
1	Battery information	Easy	Search how many minutes is remained to drive and read it for instructor.	36
2		Easy	Search how many kilometres is remained to drive and read it for instructor.	397
3	Map and navigation	Hard	Type “Oxford Street” by touchscreen keyboard and click “Enter”.	
4		Hard	Type “Hotel” by touchscreen keyboard and click “Enter”.	
5	Vehicle controls	Medium	Put the suspension mode on sport.	
6		Medium	Turn off the child protection lock.	
7	Communications	Medium	Search Jessica’s phone number and read it for instructor.	03829787610
8		Medium	Search Jack’s phone number and read it for instructor.	4685087350

3.6 Pre- and post-survey

3.6.1 Pre-survey

Before taking the test, background information of all participants was recorded via a pre-survey. However, in this study the pre-survey does not only collect demographical information as normal driving experiments, but it also could obtain touchscreen usage perception of the drivers. Beside the main target of the study about driving performance and workload, driver’s perception of the new touchscreen infotainment system in the vehicles is another essential. There are many research studied about the relationship between cognitive factor (emotions, perceptions, etc) and driving performance (De Raedt & Ponjaert-Kristoffersen, 2000; Jeon & Zhang, 2013; Rapoport et al., 2013). However, there is no research specifically studied about cognitive factors associated with driving performance in using the touchscreen while driving topic. Therefore, it is necessary to investigate the relationship between driver’s perception about touchscreen display and their driving performance while interacting with that system.

Firstly, the pre-survey will introduce the respondents about the objectives of this survey and this study. Estimated time to complete and personal information guaranteed are informed to the participants in this section. Basic demographic information such as gender, age, nationality, and driving-related information was recorded. Then an introduction part about the touchscreen system in the cars to give the respondents who do not know about the system was presented. Both word and video versions to show some secondary tasks with a commercial touchscreen system were included in. Finally, a variety questions about touchscreen from driver opinions required the respondents to rate on a 5-point Likert scale. These questions were created to access driver's perception of a new touchscreen technology system in the cars. Based on a new Technology Acceptance Model (TAM model) (Rahman et al., 2018) which was developed to define factors that influenced the driver acceptance of driver support systems in the vehicles, questions were derived into eleven subjective determinants (Attitudes, Perceived usefulness, Perceived ease of use, Subjective norm, Perceived Behavior Control, Compatibility, Trust, Endorsement, Affordability, Enjoyment and Perceived risk) which could influence driver acceptance of the touchscreen system as presented as Behavioral Intention and Actual Use. A more insightful understanding about what cognitive factors could influence driving performance while carry out the touchscreen tasks was conducted based on these pre-survey questions and driving tests. The pre-survey can be seen in the Appendix part in the end of this paper.

3.6.2 Post-survey

Before and after each drive test, the NASA-TLX was delivered to the respondents to fill-in. Six questions to collect the driver's workload perception will be answered:

1. How much mentally demanding was the task?
2. How much physically demanding was the task?
3. How hurried or rushed was the pace of the task?
4. How successful were you in accomplishing what you were asked to do?
5. How hard did you have to work to accomplish your level of performance?
6. How insecure, discouraged, irritated, stressed and annoyed were you?

In each question, there is 21-gradation scale (from very low to very high) to ask the participant subjective workload when they performed their experiments. The NASA-TLX form was used from the version of National Aeronautics and Space Administration (NASA) published online. In the Appendix section, the form is included.

3.7 Procedure of simulator test

The simulator experiments were conducted in two weeks in June 2022 (from 31 May to June 10) with a pilot test in 25 May which was to test the simulator before the main tests in Transportation Science Institution in Hasselt University. The participants were invited in working hours (9am-4pm), each participant took part in the test mostly in total one hour. A gap time of thirty minutes between each participant for preparation of a new comer. Each day, there were around 4 or 5 participants to come and join the tests. In total of ten day, thirty six people took part in the tests.

3.7.1 Introduction part

Firstly, when a participant came to the simulator room, he/she received an info paper of the simulation test. The paper was given to the participants to know more about the study, privacy protection, experiment procedures. The info letter did not provide them any information that could influence their normal driving behavior. If there was any confusion or hesitation, the test instructor explained and helped the participants. The info paper is attached in the Appendix part.

Then, an informed consent will be signed by participants, they will agree on data collection and voluntary participation from them to the purpose of this study. Researcher also signs in another version of informed consent that the same and included an assurance of giving necessary information to the participants in this study. Participants can get the version had signature of the researcher.

3.7.2 Pre survey

After reading the info letter, the online survey will be filled in by the participants, they could do the survey via their phone by scanning a QR code provided by the instructor. The participants will be given about five minutes to finish their pre-survey.

3.7.3 Training part

Before coming to the real test, a practice session was taken by the participant. The session was divided into two parts: touchscreen and driving parts. In the touchscreen part, the instructor will play touchscreen task instructions records for the participants. The participants have to listen carefully and follow the instruction. This practice with touchscreen ensures they are able to hear and understand the touchscreen tasks during the real tests. After completing the touchscreen, the participants fill in a NASA-TLX survey about their experience with the secondary tasks on a touchscreen.

Next with a driving training test, the drivers were given time to drive with the simulator in a short road segment. The instructor needs to guide and explain them how to drive with this simulator until they could confidently control the simulator likely driving a normal car. The scenario of training drive is a sub-urban road with three kilometers length with two opposite lanes. During driving there was a junction in the middle of the segment with a car coming from the right turn, the drivers have to be attentive and slow down to avoid crash. This training could retake if the drivers need more drive to be familiar with the system.

3.7.4 Real test

After finishing the training session, the participant will take two real driving tests within and without touchscreen tasks. However, in order to mitigate influence of the first test on the second test which cause biased results, participants with even number orders took the test without touchscreen tasks first and vice versa. After each test included training test and two main tests, the participants filled in a NASA-TLX survey. During taking the tests, the instructor kept the silence to not distract the drivers to drive. If they feel un-well or get any trouble, the instructor will be active to help them or stop the experiment.

3.8 Dependent variables

3.8.1 Demographic variables

In the pre-survey, there were total seven demographic variables which represent basic background of drivers and their driving-related information.

- Genders (Male, Female or others)
- Age groups (Under 25; between 25-35; over 35 years old)
- Driving experience (0-5; 5-10; over 10 years)
- Driving frequency (Almost every day, more than once a week, more than once a month, less than once a month)
- Innovativeness about new modern technologies (Five levels from very low to very high)
- Touchscreen availability in current cars (With touchscreen in the car, No touchscreen in the car)
- Infotainment system usage frequency (Never, sometimes, about half the time, most of the time, always)

3.8.2 Subjective perception of drivers about the touchscreen system

The initial subjective perception of drivers about the touchscreen system was recorded by the pre-test. Eleven potential subjective determinants (Attitudes, Perceived usefulness, Perceived ease of use, Subjective norm, Perceived Behavior Control, Compatibility, Trust, Endorsement, Affordability, Enjoyment and Perceived risk) which could predict driving performance of drivers were considered as independent variables. The value of each independent variable was scaled by 5-points Likert-scale. Therefore, these variables are ordinal scale with the outcomes from 1 to 5.

3.9 Independent variables

3.9.1 Touchscreen performance variables

With touchscreen tasks that driver's performed during driving, each task with the touchscreen was recorded as "success" if the drivers could carry out the task with a correct answer, as "fail" if the drivers could perform but with a wrong answer, and as "miss" if they could not perform the task.

After all participants finished the driving tests, the percentage of success, fail and miss for each task were calculated.

- With touchscreen task performance:
  - Success percentage of touchscreen task performance in each touchscreen task for the all participants.

- Fail percentage of touchscreen task performance in each touchscreen task for all participants.
- Miss percentage of touchscreen task performance in each touchscreen task for all participants.

3.9.2 Driving performance variables

Driver's responses with a pedestrian suddenly passed the street without a zebra line in the city street were recorded as an driving performance measure. The driver responses with crossing pedestrian include some variables such as crash numbers with pedestrians, pedestrian detection rate, distance from starting to push braking pedal to the pedestrian position. The instructor also observed their driving and performance behavioral during the whole time of the tests and recorded it in a test note.

The output data of the driving simulator was extracted after the driving test finished and recorded as four groups as follows:

- With critical events (crossing pedestrian)
    - Crash numbers with crossing pedestrians (crashes): number crashes for each main test .
    - Success rate of pedestrian detection.
    - Braking distance of vehicle approaching a crossing pedestrian.
- With car-following tasks:
    - Headway (meter): Distance between the driven vehicle and the preceding vehicles.
- General driving performance over the route:
    - Average of longitudinal speed (kilometers/hour): average of vehicle speed.
    - Standard deviation of lateral position (meters): the amount of weaving the car or considered as a measure of car controlling ability.

3.9.3 Subjective workload variables

NASA-Task Load Index is one of the most widely used form to assess subjective workload of any tasks. The NASA-TLX form assesses driver's subjective workload in six multidimensions of task performance included as follows: Mental demand, physical demand, temporal demand, overall performance, effort, and frustration. Output data was recorded in each dimension by 21 point-scale which ranked by drivers.

3.10 Analyses

3.10.1 Analysis software

The data was processed using SPSS (IBM Statistic 28) and Microsoft Excel (Version 2206).

3.10.2 *Descriptive statistics*

Descriptive statistics were conducted to examine demographical information of drivers, touchscreen performance while driving, driving performance of drivers when using and not using the touchscreen , subjective assessment on NASA-TLX in both three drives (practice, without touchscreen and with touchscreen) and driver's perception about the touchscreen system in the vehicles.

3.10.3 *Compare differences*

Because a sample group of drivers carried out both two main driving tests with and without touchscreen and driving performance measures were normally distributed. A paired T-test statistic with a 95% confidence level was applied to test the differences of driving performance variables between two tests (with and without touchscreen).

A Wilcoxon matched-pairs signed rank test was used to compare difference between two experiments (No touchscreen and with touchscreen tasks) of a paired measurement (success rate of pedestrian detection) of a driver for a non-normal distribution.

Because the touchscreen performance is represented as a nominal variable (success, fail or miss) in touchscreen tasks, and the road types (highway and urban road) and driving task (no task, car following task and pedestrian crossing task) are as two categorical variables. A Chi-Square test was applied to investigate that the success rate of performing touchscreen tasks is related to road types and driving tasks.

3.10.4 *ANCOVA analysis.*

To investigate more in the effect of other factors that could influence the relationship between touchscreen usage and driving measures. A repeated measures analyses of covariate (ANCOVA) with a 95% confidence level were conducted for average speed and SDLP. The ANCOVA analysis for each driving measure in each speed zone was separately calculated. It means that there are total eight dependent variables (average speed in zones 50, 70, 90, 120 and SDLP in zones 50, 70, 90, 120). The touchscreen usage (No and with touchscreen) was served as within-subjects variables. Covariates such as touchscreen performance (Success rate) and individual demographics (genders, age groups, driving experience, driving frequency, innovativeness, touchscreen availability and touchscreen usage frequency) were included in the ANOVA model as potential factors affected driving measures. After correction of violation sphericity to meet the assumption of ANCOVA, corrected F value and p-value were calculated. To avoid multicollinearity between covariates to follow the homogeneity of within-group, means of continuous covariates (success rate and age) were recentered.

3.10.5 *Multiple linear regression.*

To answer the research question about subjective perception of drivers about the touchscreen system in the pre-test which could influence driving performance when employing a touchscreen. A multiple linear regression was applied to predict the influenced factors on driving performance. Firstly, a correlation analysis to determine the degree of correlations between independent variables (Attitudes, Perceived usefulness, Perceived ease of use, Subjective norm, Perceived Behavior Control, Compatibility, Trust, Endorsement, Affordability, Enjoyment and Perceived risk) and dependent variable (average speed and standard deviation of lateral position). The correlation cannot explain the casual relationship however it could bring some potential relationship between dependent variable and independent variables. In additional, if there is any highly correlated relationship between each independent variable indicated by correlation coefficient greater than 0.9, then a multicollinearity in a linear regression model happened could not give true predictors of the dependent variable and less reliable statistical inferences. A removal of highly correlated variables was employed to avoid the multicollinearity. After the correlation analysis, a multiple linear regression was modeled to find the relationship between subjective perception of the touchscreen and driving performance while using the touchscreen.

3.10.6 ANOVA analysis with repeated measures

With NASA-TLX, to compare subjective workload of drivers between three driving tests (practice, with touchscreen and without touchscreen) within the group of drivers, an ANOVA with repeated measures at a 95% confidence level was used to find the significant difference between three test conditions of each dimension. Post-hoc analyses with Bonferroni adjustment reveal significant difference by pairs of each two tests.

4 RESULTS

4.1 Demographical information of participants

A number of 36 participants took part in and completed the pre-survey, the driving simulator test and the NASA-TLX in two week of experiment. There was no participants experienced simulator sickness. After data validation process, participant with ID number 28 was removed from the sample, the driving performance of this drivers was defined as a outlier of the sample with violated speed in all zones (average in zone 50: 84km/h; zone 70: 107km/h), in addition, the experiment instructor observed this driver was not aware of speed limit and having risky driving behaviors such as aggressive speeding, overtaking in cyclist lane and inconsistent speed. Therefore, it was true to eliminate this driver's data from the data set. After that, the data correction of all data set for invalid and missing data was implemented for the data set.

- Participant background.

After outliers data removal, validated data for 35 participants was used for the data analysis stage. A descriptive data about the background of sample drivers. There were 22 males, 12 females and 1 from other genders, all drivers participated with a valid typed B license. The age range was between 19 and 42 years old with a mean age of 27.63 years old (SD=6.03). The age was be divided into three age groups with 13 drivers under 25 years old, 16 drivers between 25-35 years old and 6 drivers over 35 years old. With regard to driving experience, 51.4% drivers have driving experience under 5 years, 25.8% and 22.8% drivers with experience of 5-10 years and over 10 years respectively. In terms of driving frequency, 54.2% of participants drives every day, 22.8% drives more once per week and the percentages of drivers who drive less than once per week and more than once per month are equal 11.4%.

- In-vehicle infotainment system in participant cars.

Regarding touchscreen system in the driver's cars, there is 68.6% of all participants having an infotainment system in their vehicles. In particular, there is about 30.43% of driver's vehicle installed physical and touchscreen system, while voice recognition and rotary controller account for 20.29% and 15.94% in participant's cars. Trackpad with display interface is employed by the least percent with only 2.9% (see FIGURE 10).

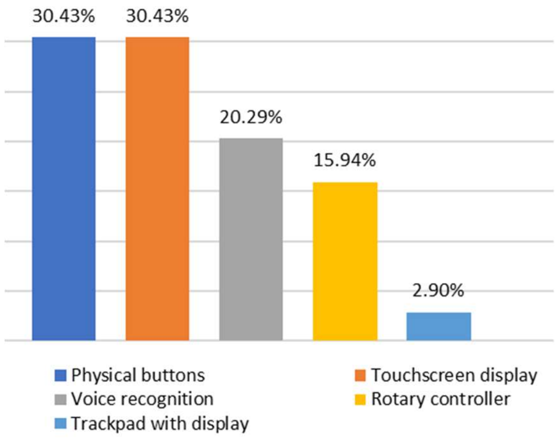


FIGURE 10 In-vehicle infotainment systems in participant cars.

With the people who have the in-vehicle infotainment systems, 14.3% participants sometimes use the system, 5.7% use about half the time, 34.3% employ the touchscreen most of the time on drive, while 14.3% always manipulate the system when driving with their cars. During interacting with the infotainment system, listening to music is the most used tasks with 17.42% of participants carried out. Followed by navigation, radio, receive message, make and answer the phone calls and safety features control with percentages of usage are more than 10% for each. Sending messages, other tasks, accessing to vehicle information, using the contact list to call and air condition adjust are less performed with the infotainment system compared to other tasks (see FIGURE 11).

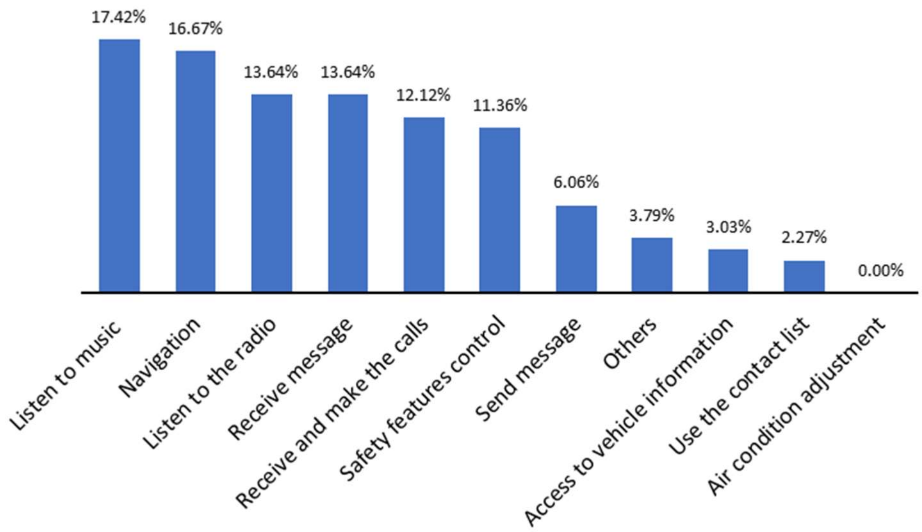


FIGURE 11 In-vehicle infotainment system task usage.

4.2 Touchscreen impacts on driver's performance

4.2.1 Driver's performance in safety-critical events (crossing pedestrian in urban zone)

- Success rate of pedestrian detection.

The success rate of pedestrian detection when the vehicle is reaching to a pedestrian suddenly crossing the street without any zebra line, is an indicator of attention capacity of the drivers. During driving, most of attention capacity is used for central vision or straight vision, and less awareness of peripheral stimuli (e.g. crossing pedestrian), therefore, peripheral stimuli detection has been used in many simulator research as a measure of attention distribution (Shinar, 2017). The higher attention of drivers, the higher percentage of peripheral stimuli detection.

In this case, to avoid the crash between their vehicles and the pedestrian, the driver must detect the pedestrian from a distance and press the brake pedal to stop before the pedestrian. With each successful detection, the pedestrian detection was counted by the brake pedal percentage from output data of simulator before reaching the pedestrian. If the drivers did not press the brake pedal, there would be no brake pedal percentage data and it was considered as no pedestrian detection. In each test which were no touchscreen or with touchscreen tasks, there were two times of stopping in front of pedestrian.

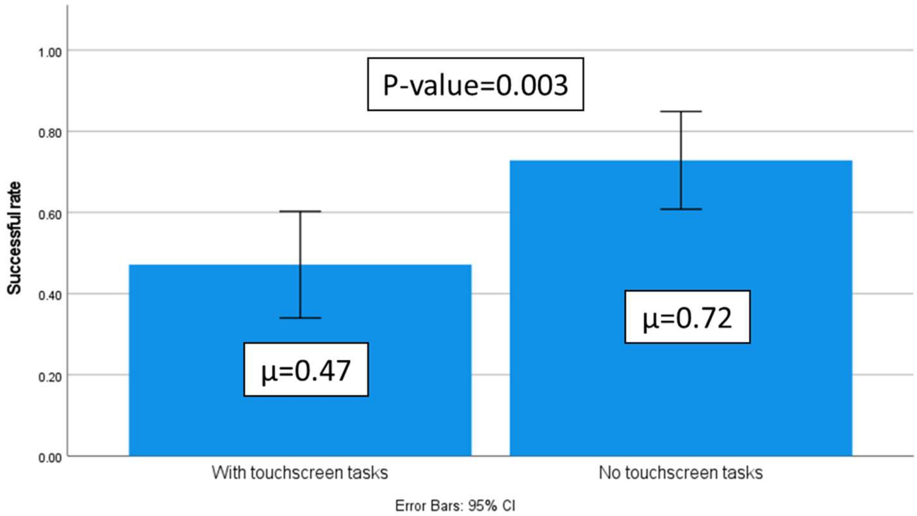


FIGURE 12 Success rate of pedestrian detection in each test: With touchscreen tasks and no touchscreen task.

Figure 12 shows the means of successful detection rate of two tests (No touchscreen and with touchscreen tasks), the difference was found between two test with 47.14% of success in detecting crossing pedestrian in touchscreen task test, while with no touchscreen task test the successful rate was 72.86%. The difference also was proven as statically significance of 95% confidence interval with p-value ($0.003<0.05$). Therefore, when the drivers performed a touchscreen tasks, the success rate of detecting a crossing pedestrian was reduced compared to no usage of touchscreen.

- Braking distance of vehicles heading a crossing pedestrian.

After detecting the crossing pedestrian, the drivers had to press the brake pedal to stop the vehicle before it collided with the pedestrian. The hypothesis here assumed that the participants drove the cars in no using touchscreen test possibly detect the pedestrian sooner than when they carried out both driving and touchscreen tasks, because the touchscreen could cause visual and manual distraction on the drivers, lead to later pedestrian detection and braking responses. In order to measure the pace of pedestrian response from drivers between two tests, braking distance from braking point to pedestrian location was recorded.

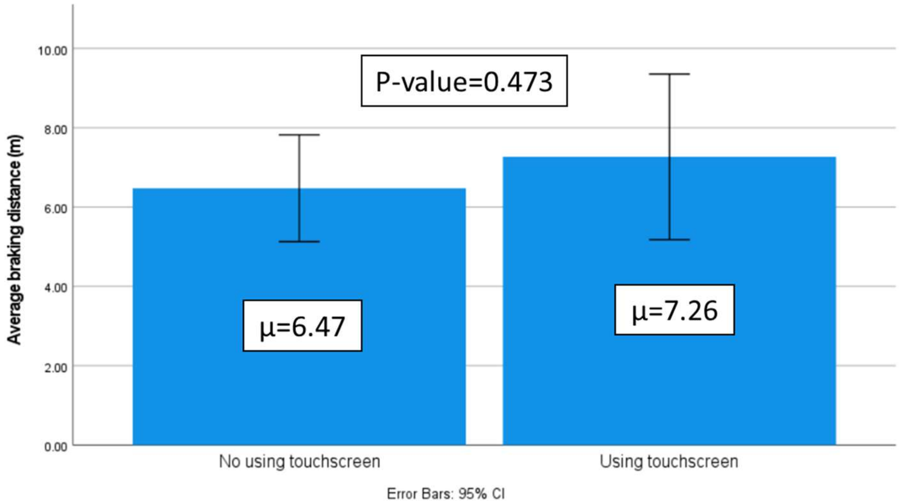


FIGURE 13 Average braking distance of crossing pedestrian detection of drivers in no touchscreen and touchscreen usage tests.

Comparing 24 valid samples of drivers who were able to detect and press the brake pedal over 35 participants in both two driving tests, the FIGURE 13 illustrates the average braking of two tests within and without touchscreen tasks. Surprisingly, as we can see that in the test with usage of touchscreen the average braking distance was longer than that of no touchscreen usage (6.47<7.26 m). However, the p-value (0.473>0.05) of paired T-test is greater than p-value of 95% confident level. Therefore, there is no statistically significant difference of braking distance between two tests. In addition, it is not enough evidence to conclude that using a touchscreen lead to a shorter braking distance as well as slower braking response to a crossing pedestrian.

- Crash numbers with crossing pedestrian.

Another factor that indicates the driver's attention is crash numbers with the crossing pedestrian in both tests. In each test, there were two events that the drivers had to stop prior the pedestrians. However, if the drivers were distracted then be late or not able to detect the pedestrians, they would hit the pedestrian. Therefore, numbers of crashes with pedestrians was used to measure the attention capacity of the drivers in two tests. The crash numbers with pedestrian were recorded automatically by the simulation system in each test.

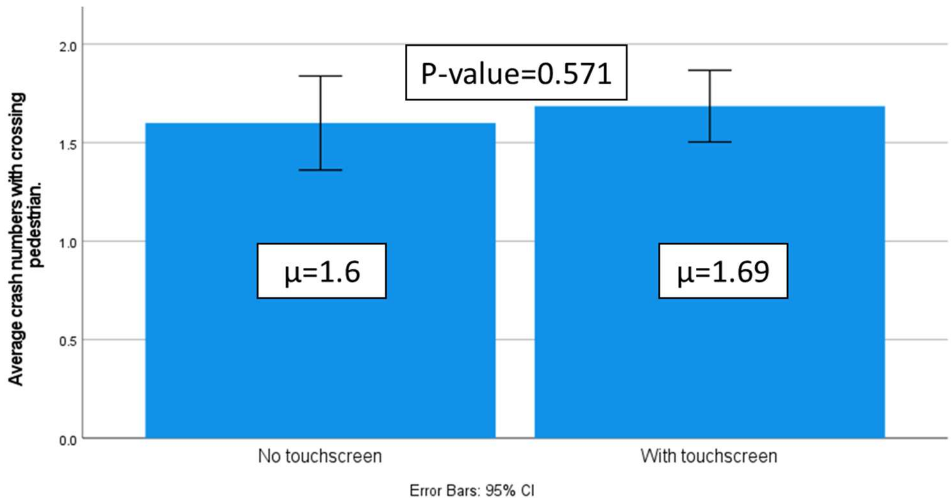


FIGURE 14 Crash numbers with crossing pedestrian in two tests: No touchscreen and with touchscreen task

In this test, a paired T-test is also used to compare the means of crash numbers in each test. Specifically, average numbers of crashes with crossing pedestrian in no touchscreen task and with touchscreen task tests were 1.6 and 1.69 respectively. However, the two results are non-statistically different each other because the p-value (0.571>0.05) is higher than 0.05. Hence, it is not enough evidence to assume that using a touchscreen could lead a higher tendency of more crashes with a crossing pedestrian.

4.2.2 Touchscreen task performance

- Touchscreen performance among different tasks

During driving on the road in the tests with touchscreen tasks, the drivers simultaneously drove the car and performed secondary tasks. If driver's attention is overload or they feel frustrated with the driving tasks or secondary tasks, the driving task will be apparently prioritized over the secondary tasks with touchscreen. Any signs of decline in touchscreen task performance such as long completed time, miss to perform the task or doing the task incorrectly are indicators of attention impairment. In this study, success percentage of doing the secondary tasks represents the touchscreen performance while driving. The percentage of success tasks was divided into groups of eight touchscreen tasks which the drivers were instructed to carry on in the tests with touchscreen. FIGURE 15 shows success , fail and miss rate of each and the overall task of 35 drivers in the test, with searching remaining time to drive in the battery information section of touchscreen system is the lowest success rate among the touchscreen tasks with 66%. The success percentage when typing hotel in navigation section is the highest with 94%. In general, most of secondary tasks with touchscreen were successful performed by all drivers with 82% of the all tasks completed, 10% fail to perform the test and only 8% of participants missed to do the tasks. The results also indicate that two tasks (searching remaining time to drive and turn on child-lock protection) which were performed during responding with a crossing pedestrian had the highest percentage of miss tasks around 20% of participants. In addition, two tasks on the highway when following leading cars were also experienced high percent of failure around 20% but the missing rate is still lower than driving approached a crossing pedestrian.

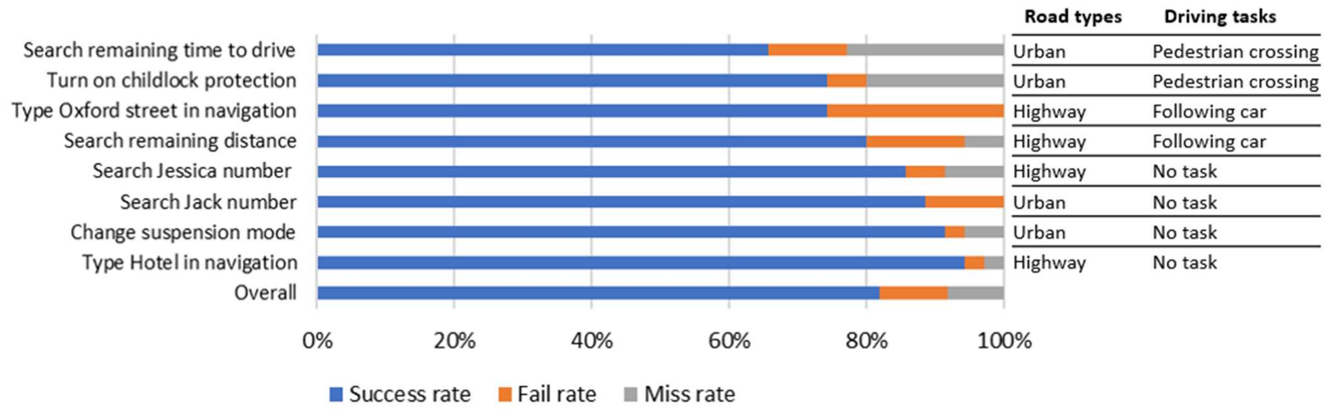


FIGURE 15 The percentage of touchscreen performance in different tasks, road types and driving tasks accordingly.

- Touchscreen performance between road types and driving tasks.

As be seen above, the task results could be possibly based on the road types and driving tasks that they are mainly performed besides the touchscreen tasks. Several studies prove that road condition (intersection, highway, urban way, etc.) and roadside objects (advertisement signs, traffic signs, stores, houses, natural scenes, billboards, pedestrian, etc.) have a relationship on visual attention and eye movement (Nakayasu et al., n.d.; Shinar, 2017). Also, during doing the test, the participants performed the car following tasks and responded with crossing pedestrian, due to limited attention capacity, the touchscreen task performance could be affected if driver's attention is overload or frustrated. Therefore, there is possibility of relationships between touchscreen task performance, road types and driving tasks.

After doing the Chi-Square test for each categorical test with touchscreen performance, there was a significant association between task performance and driving tasks $\chi 2= 32.199$, $p < .001$. Similarly, between task performance and road types the association is also significant $\chi 2= 6.656$, $p=.439$. Therefore, touchscreen task performance could be influenced by both driving tasks (car following, pedestrian response) and road types (highway and urban road) . The graphs below depict how the driving tasks and road types influence the touchscreen task performance.

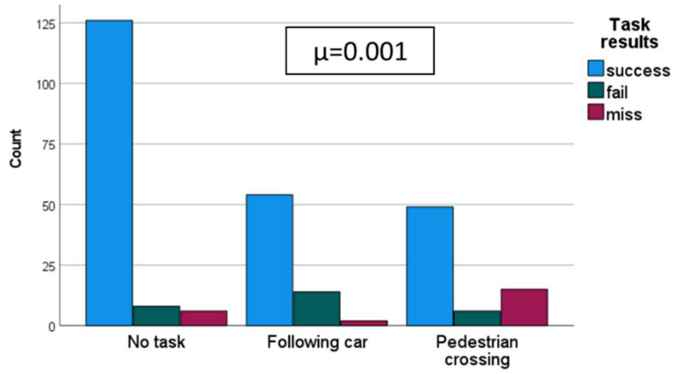


FIGURE 16 Distribution of touchscreen performance based on driving tasks.

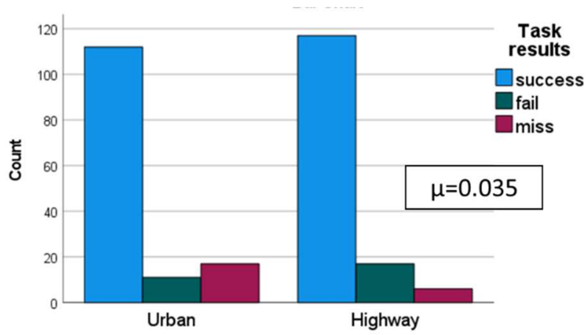


FIGURE 17 Distribution of touchscreen performance based on road types.

4.2.3 Driving performance on following tasks

- Following distance

During driving on each test, drivers had to carry out two car-following tasks on the highway segments. In the test with touchscreen tasks, the drivers performed car-following task while searching kilometres remaining, then in second car following task was with a navigation task by typing "Oxfords street". In these car-following tests, following distance is distance between simulator and leading vehicles, the distance is compensated safely by the drivers. And this parameter has been included in many distraction behaviour research in car-following task (Cooper et al., 2009; Li et al., 2019).

In this following distance assessment of car-following task, a paired T-test was employed to test whether there is any difference in following distance between no touchscreen and with touchscreen task tests. The test results depict that there are statistically significant differences of following distance between no touchscreen task and with touchscreen task in both searching remaining kilometres ($t=-3.508$, $p=0.001$) and typing Oxfords street task ($t=-6.490$, $p<0.001$). Specifically, following distance is increased when the drivers performing touchscreen tasks when compared with no touchscreen task (see FIGURE 18 and FIGURE 19). Hence, the usage of touchscreen could cause a longer headway in car following task.

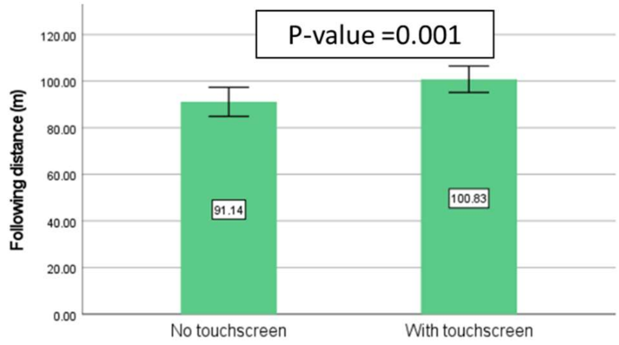


FIGURE 18 Following distance while performing searching kilometer task.

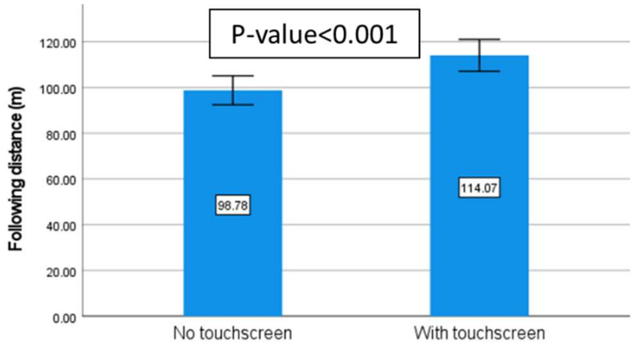


FIGURE 19 Following distance while performing typing Oxfords street.

4.2.4 General driving performance on the routes

- Average speed and standard deviation of lateral position performance

Average speed and standard deviation of lateral position (SDLP) are two common parameters in assessment of the driving performance. Many research has studied about different factors that affect the speed choice and maneuver (Shinar, 2017). A research found a reduction in driving speed when drivers committed in dual-tasks, or in another study showed lane keeping could be varied by attention capacity (Cooper et al., 2009; Cuenen et al., 2015).

According , there are statistically significant differences between two main tests in average speed on both four zones (50, 70, 90 and 120). Compared to no usage of touchscreen, in the test with touchscreen tasks the drivers tended to drive slower in all zones. Besides, in lane keeping performance the SDLP in the all route is also marginally significant different between the two tests (t=1.81, p=0.08). However, there is only one statistically significant difference in SDLP in zone 50 (t=-16.10, p=0.001). The maneuver controllability was decreased with a larger SDLP in touchscreen tasks than no touchscreen task drive.

TABLE 3 Paired T-test analysis of average speed and SDLP between two main tests (No and with touchscreen)

		Mean	Std. Deviation	Mean difference	t-value	Two-sided p
Pair 1	Average speed in Zone 50 (No touchscreen)	46.54	4.75	2.12	3.14	0.00*
	Average speed in Zone 50 (With touchscreen)	44.42	5.63			
Pair 2	Average speed in Zone 70 (No touchscreen)	65.22	7.64	4.34	3.03	0.00*
	Average speed in Zone 70 (With touchscreen)	60.88	9.03			
Pair 3	Average speed in Zone 90 (No touchscreen)	85.16	11.48	3.12	2.10	0.04*
	Average speed in Zone 90 (With touchscreen)	82.03	10.29			
Pair 4	Average speed in Zone 120 (No touchscreen)	95.33	18.40	3.89	2.13	0.04*
	Average speed in Zone 120 (With touchscreen)	91.44	19.26			
Pair 5	SDLP in the route (No touchscreen)	2.67	0.28	0.11	1.81	0.08
	SDLP in the route (With touchscreen)	2.56	0.43			
Pair 6	SDLP in zone 50 (No touchscreen)	0.32	0.14	-0.46	-16.10	0.00*
	SDLP in zone 50 (With touchscreen)	0.78	0.10			
Pair 7	SDLP in zone 70 (No touchscreen)	0.16	0.06	0.00	0.02	0.99
	SDLP in zone 70 (With touchscreen	0.16	0.09			
Pair 8	SDLP in zone 90 (No touchscreen)	0.28	0.16	-0.02	-0.58	0.56
	SDLP in zone 90 (With touchscreen	0.30	0.09			
Pair 9	SDLP in zone 120 (No touchscreen	0.83	0.45	0.08	0.88	0.38
	SDLP in zone 120 (With touchscreen)	0.75	0.35			

*<0.05

- Interactions between touchscreen usage and touchscreen performance, driver's demographics on driving performance.

TABLE 4 Repeated measures ANCOVA for driving measures (Average speed, SDLP) based on independent variables.

Driving measures	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Average speed	Zone 50		Zone 70		Zone 90		Zone 120	
Touchscreen usage	1.40	.246	.899	.352	4.28	.049*	4.06	.054
Touchscreen usage * Success rate	.210	.651	.143	.708	.517	.479	1.26	.272
Touchscreen usage * Gender	1.32	.260	.815	.375	9.62	.005*	.752	.394
Touchscreen usage * Age	.284	.598	1.26	.270	3.59	.069	1.27	.269
Touchscreen usage * Driving experience	.288	.596	2.12	.157	7.25	.012*	8.07	.009*
Touchscreen usage * Driving frequency	.943	.340	1.90	.180	5.87	.023*	6.09	.020*
Touchscreen usage * Innovativeness	.380	.543	1.54	.225	9.25	.005*	.003	.958
Touchscreen usage * Touchscreen availability	6.68	.016*	8.10	.008*	22.0	.001*	1.71	.202
Touchscreen usage * Touchscreen usage frequency	4.22	.050*	8.03	.009*	17.2	.001*	2.57	.121
SPLD	Zone 50		Zone 70		Zone 90		Zone 120	
Touchscreen usage	2.29	.142	.452	.509	18.3	.001*	2.97	.096
Touchscreen usage * Success rate	.793	.381	.257	.617	.248	.623	.002	.963
Touchscreen usage * Gender	.247	.624	4.79	.040*	.415	.525	.020	.890
Touchscreen usage * Age	1.47	.235	2.94	.101	9.04	.006*	.488	.491
Touchscreen usage * Driving experience	1.83	.187	.072	.791	10.8	.003*	.680	.417
Touchscreen usage * Driving frequency	.059	.810	1.93	.178	1.43	.243	.233	.633
Touchscreen usage * Innovativeness	.199	.659	.140	.712	10.9	.003*	1.52	.228
Touchscreen usage * Touchscreen availability	.001	.979	.054	.819	4.07	.054	1.71	.201
Touchscreen usage * Touchscreen usage frequency	.107	.746	.360	.555	3.53	.071	1.83	.188

*<0.05

From the repeated measures ANOVA table, it is clear from the significance value that there are significant interaction between touchscreen usage and two covariates: touchscreen availability and touchscreen usage frequency on speed average in zones 50, 70 and 90. In addition, gender, driving experience, frequency and innovativeness of drivers have also effects on relationship of touchscreen usage and average speed in zone 90. In zone 120, there are significant interaction between touchscreen usage and driving experience, driving frequency for average speed performance.

In SDLP performance, the touchscreen usage significantly influenced the SDLP in zone 90 and 120. The gender also has interaction with touchscreen usage in zone 70 and zone 90. The remaining covariates (age group, driving experience, driving frequency, innovativeness, touchscreen usage and touchscreen usage frequency) have no significant interaction with touchscreen usage in SDLP performance.

- Influences of touchscreen driver's perceptions on driving performances while using touchscreen.

From the analysis table of correlation between independent variables (TABLE 5), there was a highly correlated relationship between Attitude and Perceived usefulness (r=.95, n=35, p<0.001). A removal of one variable (Perceived usefulness) was executed. Therefore, ten remaining independent variables were included in the multiple linear regression.

TABLE 5 Correlation analysis between subjective perception independent variables.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
P1	1										
P2	.94**	1									
P3	.675	.707	1								
P4	.465	.450	.557	1							
P5	.484	.513	.540	.600	1						
P6	.507	.520	.285	.277	.507	1					
P7	.653	.651	.587	.644	.692	.592	1				
P8	.754	.742	.695	.514	.541	.383	.787	1			
P9	.741	.697	.645	.446	.614	.445	.669	.804	1		
P10	.083	.145	.125	.069	.096	.042	.09	.159	.038	1	
P11	.002	.025	-.038	.186	.323	.28	.161	-.059	.07	-.255	1

P1: Attitude; P2: Perceived usefulness; P3: Perceived ease of use; P4: Subjective norm; P5: Perceived behaviour control; P6: Compatibility; P7: Trust;P8: Endorsement; P9: Enjoyment; P10: Affordability; P11: Perceived risk.
*>0.9.

TABLE 6 ANOVA tests significance of the models correspondingly in driving performance.

	Sum of Squares	df	Mean Square	F	Sig.
Average speed in zone 50	399.879	10	39.988	1.413	0.234
Average speed in zone 70	1295.402	10	129.54	2.104	0.066
Average speed in zone 90	977.963	10	97.796	0.896	0.551
Average speed in zone 120	4946.902	10	494.69	1.549	0.183
SDLP in zone 50	0.109	10	0.011	1.002	0.469
SDLP in zone 70	0.061	10	0.006	0.723	0.695
SDLP in zone 90	0.059	10	0.006	0.665	0.745
SDLP in zone 120	0.409	10	0.041	0.255	0.986

For each driving performance dependent variable, an ANOVA analysis tests the regression model could be significantly predicted by the predictors. As the results shown in that there was no statistically significant relationship between the predictors and the dependent variable (p-value>0.05). Therefore, there was no evidence about the driving performance could influenced by any of subjective perceptions of driver about the touchscreen system.

4.3 Subjective workload of drivers

The subjective workload NASA-TLX survey was employed to assess driver's perception of six dimensions: Mental demand, physical demand, temporal, performance, effort and frustration. The diagram below (FIGURE 20) intuitively depicts mean scores of each dimension in three test conditions: Practice drive, no touchscreen drive and with touchscreen drive. For each dimension of driver's workload, a subjective subscale of 20 points was filled out by the drivers, the maximum and minimum scores are respectively 0 and 20 points. The detail mean scores and standard deviations for NASA-TLX survey is attached below in .

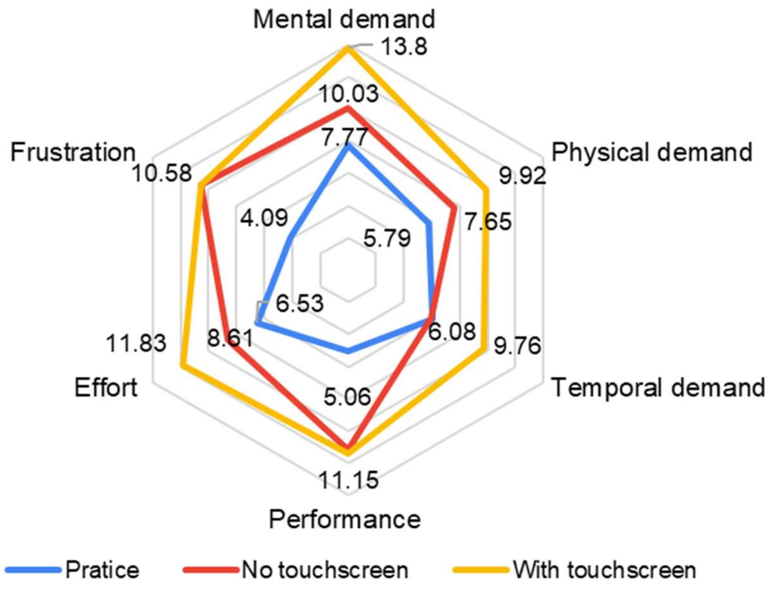


FIGURE 20 NASA-TLX scores of all participants in six dimensions of perceived workload.

TABLE 7 Means and standard deviations of NASA-TLX scores of participants.

Subjective workload	Practice	No touchscreen	With touchscreen
Mental demand	7.77 (4.20)	10.03 (3.70)	13.8 (3.68)
Physical demand	5.79 (3.59)	7.65 (4.39)	9.92 (4.52)
Temporal demand	6.08 (4.00)	5.97 (4.09)	9.76 (4.37)
Performance	5.06 (3.75)	11.15 (5.60)	11.41 (4.61)
Effort	6.53 (4.20)	8.61 (4.70)	11.83 (3.99)
Frustration	4.09 (3.21)	10.58 (4.96)	10.59 (4.47)

An ANOVA with repeated measures was used to find the significant difference between three test conditions of each dimension and post-hoc analyses with Bonferroni adjustment (see) reveal significant difference by pairs of each two tests. Firstly, with driving practice the mean scores in five dimensions (mental, physical demand, performance, effort and frustration) are significantly lower than real driving tests without (-2.26, $p<0.05$; -1.85, $p<0.05$; -6.09, $p<0.05$; -2.09, $p<0.05$; -6.49, $p<0.05$) and with touchscreen (-6.03, $p<0.05$; -4.13, $p<0.05$; -3.68, $p<0.05$; -5.30, $p<0.05$; -6.50, $p<0.05$), only score in temporal demand is insignificant lower than drive with no touchscreen (0.11, $p=1.00$). With no touchscreen task drive, metal, physical temporal demands and effort scores of drivers are significant smaller than these of with touchscreen drive (-3.76, $p<0.05$; -2.27, $p<0.05$; -3.79, $p<0.05$; -3.21, $p<0.05$). Only performance and frustration rates are not significant different between two tests

(-0.27, p=1.00; -0.01, p<1.00). In addition, during drive with touchscreen tasks, the participants perceived highly mental demanding compared to other aspects (μ=13.8).

TABLE 8 Multiple comparisons: Mean differences and p-value of workload dimensions between three test conditions.

		Mental demand		Physical demand		Temporal demand		Performance		Effort		Frustration	
I	J	I-J	p	I-J	p	I-J	p	I-J	p	I-J	p	I-J	p
1													
	2	-2.26	0.01	-1.85	0.02	0.11	1.00	-6.09	0.01	-2.09	0.04	-6.49	0.01
	3	-6.03	0.01	-4.13	0.01	-3.68	0.01	-6.35	0.01	-5.30	0.01	-6.50	0.01
2													
	1	2.26	0.01	1.85	0.02	-0.11	1.00	6.09	0.01	2.09	0.04	6.49	0.01
	3	-3.76	0.01	-2.27	0.01	-3.79	0.01	-0.27	1.00	-3.21	0.01	-0.01	1.00
3													
	1	6.03	0.01	4.13	0.01	3.68	0.01	6.35	0.01	5.30	0.01	6.50	0.01
	2	3.76	0.01	2.27	0.01	3.79	0.01	0.27	1.00	3.21	0.01	0.01	1.00

1: Practice drive; 2: No touchscreen drive, 3: With touchscreen drive.

5 DISCUSSION

In this study, the impacts of a touchscreen on driving performance and subjective workload of drivers were the main objectives to achieve. In order to accomplish the main targets of the study, the main research question was divided into several sub-questions to answer. In driving performance, the research investigated the driver's levels in both employing the touchscreen system and controlling the vehicles. The touchscreen performance of drivers is represented by their success, fail or miss percentage to do the touchscreen tasks in normal drive, car-following and crossing pedestrian events. Speed and standard deviation of lateral position degradation which possibly caused by the touchscreen were examined in order to investigate the possible negative impacts of the touchscreen. In additional, the possibilities of driver's demographics and driver' subjective perception about the touchscreen system influenced driving performance impairments were also explored. On the other hand, the investigation about driver workloads while driving with and without using the touchscreen was conducted to reveal potential cognitive overload on the drivers. The study basically answered the main question through the relevant outcomes.

5.1 Driver's performance in driving with touchscreen tasks

5.1.1 Driver's performance in critical events

In driving, an increase in workload process for foveal target such as infotainment system in-vehicle or mobile usage leads to a decrease in peripheral attention (Harms & Patten, 2003). Indeed, in this study of touchscreen, the crossing pedestrian task is one of peripheral assignment for drivers which downgrade driver's ability in pedestrian detection while using the touchscreen. The results reveal that the probability of pedestrian detection was reduced in driving with touchscreen in comparison with no touchscreen usage. The same results were observed in another study of peripheral detection task (PDT) with telephones task (Patten et al., 2004). Interacting with a touchscreen also witness a decline in detection rate of stimuli compared to voice control and driving control (Ramnath et al., 2020).

On the other hand, although the speed of reaction of drivers when already detected the crossing pedestrian of employing a touchscreen represented by braking distance to the pedestrian was longer than no usage of touchscreen, however, the significant difference has not enough evidence to conclude. Nevertheless, in another research reaction time with stimuli of using a touch interface remained slowest responses as to voice and driving control (Ramnath et al., 2020). Or another reaction measure such as in brake initiation at pedestrian crossings in another simulator study, the brake initiation with visual distraction tasks was decreased compared to no visual distraction (Cuenen et al., 2015). This inconsistence between current study and recent research happens, possibly because of low crossing pedestrian detection rates which could lead biased results. Other further studies with respect to peripheral stimuli in using the touchscreen should be carried out.

Similarly, as the responses to crossing pedestrian the average number of crashes with crossing pedestrians in touchscreen tasks was not significant different from no task. The crash rates of both two main tests were relatively high because of low detection rate and low reaction speed from drivers. However, in recent research about distraction the crash numbers between visual-cognitive and no distraction drives, the number of crashes in distraction scenarios were almost double than that of no distraction (Cuenen et al., 2015). The concerns about inattention-related crashes with pedestrians is true because in an in-depth investigation of real crash report from Norway in-vehicle infotainment system was the second highest factor that contribute to crashes with pedestrian right after mobile phone usage (Sundfør et al., 2019). Late detection is the major cause lead to pedestrian crashes with cars, because of insufficient attention allocation between foveal and peripheral vision. Therefore, peripheral-related crashes is higher potentially risky than straight-ahead risky events, specially when driver's attention is occupied by in-vehicle touchscreen tasks.

5.1.2 Touchscreen performance

With regards to touchscreen task performance, the success rate of each tasks varied not based on task difficulty but it depended on the main driving task (no task, following tasks and pedestrian responses) and the driving road types (Highway and Urban roads). This study is corresponded with other research, in many previous studies the road environment (highway and urban roads) and could influence the driving attention in some of degrees (Shinar, 2017) because of more stimuli in the city rather than on the highway. The drivers in the city were not only distracted by the touchscreen display but also by the environmental stimuli, their attention capacity was shared to multiple distraction sources.

5.1.3 Car-following tasks

Through the research, a typical driving task as car following performance when carrying out touchscreen tasks was investigated. The results emphasize empirical research about headway in car-following tasks, there is an increased tendency in following distance while being distracted by any sources of distraction included touchscreen tasks (Blanco et al., 2006b; Cuenen et al., 2015; Ramnath et al., 2020). In our study, another point was discovered that the more complex tasks, the more longer following distance. On the whole, these above results implies that when drivers are driving with some of the distraction involved, they tend to leave a larger margin between the leading cars, this behavior is the result of compensation between safety and distraction, the drivers are more conscious about the safety hence attempting to reduce speed to avoid the risks.

5.1.4 General driving performance

The increase of driver's conspicuity in safety compensation in driving with touchscreen tasks was revealed in average speed on both four zones 50, 70, 90, 120. With average speed in driving test with no touchscreen was significantly higher than average speed of with a touchscreen. This is consistent with other studies in touchscreen impacts on driving speed (Hagiwara et al., 2013; Ramnath et al., 2020). Steering control represented as standard deviations of lateral position in both two tests were almost the same. Except in zone 50, with higher SDLP with touchscreen than no touchscreen. However, other studies confirmed that the SDLP in touchscreen tasks is significantly greater than without touchscreen task, additionally, the SDLP in using of touchscreen is even the worst and more lane departures to compared other interfaces (Cooper et al., 2009; Hagiwara et al., 2013; Ramnath et al., 2020; Tsimhoni et al., 2004). In the above studies, the tested roads were mostly in urban or suburban with more crowded traffic flow likes in zone 50 in our study, these areas with more distraction sources which could affect drivers besides distraction from the touchscreen. Hence, the more distracted, the more larger lane deviation. On the other hand, in highway environment, because of less visual and cognitive distraction, the drivers are able to control the vehicle and the touchscreen simultaneously with less effort.

In this research, unlikely the other studies, a more in-depth analysis in participant demographical investigation was conducted by involving all recorded background information of participants into the ANCOVA models of relationship between touchscreen usage and driving measures. Interestingly, there are interaction between touchscreen employment and touchscreen experience (availability in driver 's vehicles and used frequency) on speed performance in all zones expect highways. It implies that the driver's who have more experience could be less effected by touchscreen tasks than people less or no experience. In the highways, the interaction between touchscreen usage and driving experience, frequency on speed performance are possibly happened. Moreover, in steering controllability the background of drivers seemingly not affect the SDLP whether with or without a touchscreen. The results only show a small influence of genders on the relationship between touchscreen usage and SDLP, however, this finding should be more explored in a larger sample experiment, because there is limited paper investigated this aspect. Nevertheless, in this study the age groups did not indicate any influence on driving performance in touchscreen usage. That could be because of lack of age groups in this study, the age range was only in-between younger and adult groups, no elderly people joined in the tests. Driving behavior and performance of between younger and older drivers are really different because the driving task is a high intensive assignment required effort from drivers. And older and younger drivers have different abilities and medical health, therefore their behavior in driving while interacting a touchscreen could be varied. Indeed, several studies found that the elderly people are more sensitive to the effects of distraction than other groups. They are less feasible in sharing their attention into two concurrent tasks than younger groups (Young & Regan, 2007). Therefore, in this type of distraction it should be more investigated in differences between age groups.

From the pre-survey data about the initial subjective opinions of drivers about the touchscreen system, there was no significant evidence that the driving performance could be influenced by these subjective perception. The results is understandable because the system of simulator and touchscreen system were mostly new with the participants. Therefore, it was challenging for drivers to evaluate the systems without any experience before. Hence, overestimation or underestimation the touchscreen system could be appeared after the driving tests with touchscreen tasks finished. This could lead to unexplained driving performance while using a touchscreen, if the subjective perception of drivers about the touchscreen system were assumed as predictors of the driving performance.

5.2 Driver's perception on workload and driving performance

Personal perceptions about the touchscreen task and driving performance is essential for researchers to figure out the real feeling and opinion of drivers. The participant's perception was reflected in the NASA-TLX form after each test. According the comparison between tests with and without touchscreen tasks, most of subscales in the test with touchscreen tasks were higher than no touchscreen task. Hence, in general the drivers feel over workload in some of degrees when using the touchscreen compared with normal drive. Specially, mental demand, performance and effort have the highest scores compared to other dimensions. The results are corresponding NASA-TLX records from another study about employing a navigation system during driving in different road environments (Yared & Patterson, 2020). Many studies consistently revealed that touchscreen related tasks are more mentally, temporally and effortful than other interfaces such as physical button, voice recognition (Frank et al., 2002; Noy et al., 2004). The impacts of touchscreen were not only shown in driving performance measures but also reported by the drivers. That emphasize the problem of impacts of touchscreen usage while driving in driving performance.

6 LIMITATIONS

Although the research have address the raised questions, limitations from this study are inevitable. Firstly, since the scope and scale of the study are limited to a small driving simulator research, the age groups of the study did not cover old driver group. The negative impacts could be more severe in this missing group, since many studies proved that older driver 's driving performance was greater reduced than the younger groups if they committed in attention-shared tasks due to their low visual and cognitive capacity (Alm & Nilsson, 1995; Lamble et al., 2002).

Secondly, due to the participant recruitment based on voluntary of the drivers, self-selection bias could be occurred. Especially, those think they are highly experienced to join in the test. The results could be even worse if the drivers who have low skills and experience in driving could have joined to the tests. Therefore, the study sample was represented in a low levels for the all population.

Third, the impacts of touchscreen tasks on driver's attention has not fully incorporated yet. Since the driver's attention is a subjective measurements, eye-tracking analysis was conducted mostly in simulator studies about the infotainment distraction in the cars (Hagiwara et al., 2013; Ramnath et al., 2020).

In addition, driving performance of the drivers is not represented by only average speed and standard deviation of lateral position. But there are still number of driving performance measures such as brake reaction time, car-following distance, speed, maneuver angle, acceleration and deceleration, etc. Each driving performance measure is an indicator of a driving task, thus, more driving tasks when using a touchscreen could be included in the future research to identify the impacts of the touchscreen tasks on each driving task.

Moreover, a naturalistic driving experiment should be carried out for the future research since the simulator study could not reflect the risky situations in the real-world driving. Additionally, in this simulator study the environment and driving scenarios did not completely visualize movements of the surrounding objects (cars, cyclists, pedestrians, etc.). Therefore, the results of the study should be validated based on naturalistic experiment and from subjective assessment of the participants. It could help the researchers carefully assess the impacts of the touchscreen system on driving performance.

7 CONCLUSIONS AND IMPLICATIONS

The current study discloses background information of touchscreen availability and frequency usage of a driver group and the impacts of the touchscreen on their attention and driving performance in the context of a simulator experiment. The drivers performed poorer in peripheral responses such as detection ability, braking reaction with the stimulus, however, there is not enough to conclude a more probability of collisions. Regarding secondary task performance with the touchscreen, the percentage of correct task is relatively varied on the tasks. Difficulty of the tasks is not related to the success rate outcome, but the percentage of correct tasks is more depended on the main driving tasks that are simultaneously performed with the touchscreen tasks.

In the driving performance impacts of the touchscreen, the drivers tended to be more compensated between safety and touchscreen usage. The speed and following distance in the highway and urban is lower with the touchscreen usage. However, the steering control is only shown a decrease in zone 50 with more traffic flow and other types of distraction. On the highway, the maneuver performance is remained as normal drive with no change in standard deviation of lateral position. Furthermore, experience in using the touchscreen could influence the average speed on urban roads in term of employing the system or not. On the other hand, when driving on the highways, there is an interaction between driving experience and touchscreen usage on the average speed. The changes in lateral position of vehicles are mostly unaffected by driver's demographical background. Only genders was seen as a potential factor that could influence the steering controllability. In addition, the initial subjective opinions of the drivers about the touchscreen system has no relationship with driving performance degradation.

From subjective perception of the participants, driving and interacting with the touchscreen could lead them more mentally, physically, temporally demanding and effort compared to normal drive. In addition, the weight of mental, performance and effort are ranked as the highest scores of workload. This implies that the touchscreen system distracts driver's attention and degrade driving performance not only based on numerical data collected from the simulator but from the driver's opinion.

The new touchscreen technology device is not yet prevalent in the current vehicles of the drivers. Therefore, it is a brand new research for the scientists to explore more about its impacts on the driving behavior. It is crucial to mitigate the distracted impacts of the touchscreen by multiple approach from education activities, system design, policies, etc. The awareness of potential distraction come from a touchscreen system could be enhanced in driving lessons by involving in-vehicle infotainment system practices. Raising the awareness about the adverse effects of employing a touchscreen while driving could be implemented by campaigns such as in Belgium BOB campaign to increase driver's public knowledge towards a safer driving behavior to reduce drunk driving (Wickramarachchi, 2013). The campaign could help the society in obtaining the possible negative impacts when using a touchscreen on the road then give them training program and guidelines to how to use the touchscreen safety and properly to reduce the risks from it.

The government or policy makers should issue in-vehicle infotainment system legislations penetrated in touchscreen and other modern methods of communication with the vehicles. In term of the system design, auto-manufacturers not only adhere the laws of safety for in-vehicle safety system but also improve the system to be more friendly with the users by integrating other interfaces to assist the drivers in receiving the richer feedback from the system likes voice recognition, buttons, haptic feedback from the touchscreen.

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Appendix 1 : Info Paper of the study

Title of the study: Touchscreen usage during driving
Research Institute: Transportation Science Institution - Hasselt University (IMOB - UHasselt)
Researcher: Nguyen Do Duc Khanh
Data protection officer (DPO): dpo@uhasselt.be

Dear

You are invited to voluntarily participate in a scientific study to investigate the use of touchscreens while driving.

During this study, the intention is to drive in the driving simulator as you normally would and honestly give your opinion while filling in a questionnaire.

Before you decide to take it, we would like to give you information so that you have more information about the study. Please read this information carefully. If you have any questions, ask the researcher.

➢ Participation is voluntary. A signed consent is required for participation. Even after this signed goal, you can stop at any time without giving a reason. This decision to quit has no consequences.

➢ The collected data will be treated confidentially. Anonymity is assured. Only data necessary for the conductof this study will be collected.

➢ If you would like more information, do not hesitate to contact the contact person.

Purpose and description of the study

The aim of the study is to investigate the use of touchscreen while driving.

At the end of the study, you will receive an overview of the results of the study if desired.

If you have any questions, do not hesitateto contact the researcher.

Experiment procedures.

- Sign consent form
- Driving in the driving simulator
- Completing questionnaire

Participation lasts max. 1h 15 min.

Description of risks and judgments.

Participation in this study involves virtually no risks. The only limited risk is the risk of simulator sickness while driving in the driving simulator, but this risk is rather limited due to low prevalence in young people (mainly occurs in persons aged 70 years and older) and due to short duration of scenario and only straight ahead driving (occurs especially in long scenarios with turning left/right).

Participation does not give a personal benefit, but contributes to a better understanding of traffic behavior.

Withdrawal of consent

If you stop participating, your data will not be processed.

If you participate, we ask you to:

- sign the consent form
- driving in the simulator
- complete a questionnaire

Voluntary participation

Don't hesitate to ask questions. You have the right to stop the study at any time .

If you want to participate, sign the consent form. The researcher will also check this and confirming that she has given you all the information. You will receive a copy.

Costs for participation

You will not be compensated for participation. There is no charge for participation.

Confidentiality

Participation means that you agree that the research team collects data about you (e.g. performance during ride in driving simulator and answers to questionnaire) and uses this data for research and scientific publications.

You have the right to ask what information they collect and why it is used in the study. You have the right to view and correct this information if it is incorrect.

The research team is obliged to treat collected data confidentially. Your name will therefore not be mentioned anywhere. Personal data is encrypted (your identity is replaced by an identification code during the study). Only the research team has access to data.

Information about you will be electronically processed and analyzed by the research team to determine the results. This information is secured so that others do not have access to it. The server is well secured by various mechanisms according to guidelines.

The server manager is responsible for collecting the data, processing and protecting the data in line with the Belgian legislation on the protection of personal data.

Only with permission will the data be stored for 10 years. In this way, there is sufficient time for additional analyses and publication in a scientific journal.

Contact

For more information, please send an email to nguyen.doduckhanh@student.uhasselt.be.

Appendix 2 : Pre-Survey

UHASSELT

ID number of participant

ID number

Introduction

Dear respondents

My name is Do Duc Khanh Nguyen. I am a master's student in Transportation Sciences at Hasselt University, Belgium. My promotors are Prof. dr Tom Brijs and Dr. Ariane Cuenen

This survey is carried out as part of my master thesis. My goal in this project is to obtain information about the intention of users to use a touchscreen infotainment system in the car. The touchscreen infotainment system will be described and demonstrated by means of a short video later in this survey. The final objective of this project is to formulate recommendations towards vehicle manufacturers and policymakers on how to improve user experience and road safety.

This survey takes 5 minutes to complete. Please answer all questions. More detailed instructions on how to provide your answers are provided further in the survey.

No sensitive personal data will be collected. All data collected will be stored and processed anonymously and will only be used for the purpose of this study. You are allowed to step out of this study anytime you want, without any consequences.

In case of any follow-up questions, please contact:
Nguyen.doduckhanh@student.uhasselt.be

- ◯ I agree to participate in this study and to proceed to the survey.
- ◯ I do not agree to participate in this study and to proceed to the survey

Demographic questions

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Non-binary / third gender
- ◯ Prefer not to say

When were you born

What is your nationality?

In which country do you currently reside?

Do you have a valid full license for driving a car (License category B)?

- ◯ No
- ◯ Yes

When is the last time that you drive a car.

- Today
- This week
- Last month
- Last three months
- Last six months
- Last year
- Several years ago

For how many years do you have a valid full license for driving a car (License category B)

- 0-5 years
- 5-10 years
- 10+ years

How often do you drive a car?

- Almost every day
- More than once a week
- More than once a month
- Less than once a month

I like to try out new technology

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Introduction about infotainment system

A short description of the touchscreen infotainment system.

The term "infotainment system" is a mash-up of two main functions "information" and "entertainment". The name refers to systems that provide information to drivers about the status of their car, weather conditions, traffic, radio, et cetera. These systems also serve to entertain drivers while driving such, for instance allowing to listen to music, make phone calls, send messages, et cetera. An infotainment system typically takes the form of a touchscreen or display that is mounted on the dashboard in the middle of the car as shown in the above picture.

Drivers having infotainment system

Is the car you usually drive with equipped with an infotainment system?

- Yes
- No

Please indicate below which type of interface(s) you can use to operate the infotainment system in your car. You can choose multiple interfaces!

- Touchscreen display
- Physical buttons
- Rotary controller (A rotary controller is a knob and surrounding buttons in the center console of a car used to control infotainment system)
- Voice recognition
- Trackpad with display (Trackpad is a specialized surface that can translate the motion and position of a user's fingers to a relative position on the screen of infotainment system)

- [ ] [ ] Others

How often do you use an infotainment system in your car?

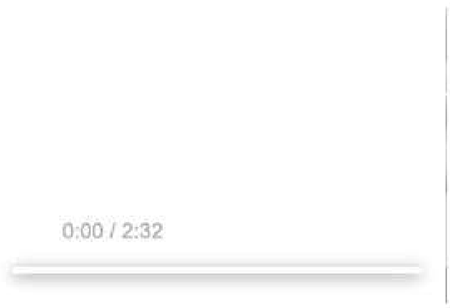
- ○ Never
- ○ Sometimes
- ○ About half the time
- ○ Most of the time
- ○ Always

Which of the below listed tasks do you REGULARLY carry out by means of the infotainment system in your car?
(You can choose multiple tasks)

- [ ] Navigation
- [ ] Listen to the radio
- [ ] Listen to music (Spotify, Youtube, Apple music, ...)
- [ ] Receive and make the calls
- [ ] Use the contact list to contact someone
- [ ] Send message
- [ ] Receive message
- [ ] Safety features control (ABS, Adaptive cruise control, Lane departure warning....)
- [ ] Air condition adjustment
- [ ] Access to vehicle information such as light, camera, mirror, engine, ...
- [ ] [ ] Other tasks

Touchscreen display introduction

The below video demonstrates some features of a touchscreen infotainment system which can be used by drivers while operating their vehicle. Please watch this video carefully because the questions to be answered below all apply to the system that is demonstrated in this video.



Likert scale for all respondents

For the questions below, please indicate the answer option that best represents your personal opinion.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
A touchscreen infotainment system such as the one demonstrated in the video would be useful to me	○	○	○	○	○
A touchscreen infotainment system such as the one demonstrated in the video, would be helpful to me	○	○	○	○	○
I think the touchscreen infotainment system demonstrated in the video is easy to use.	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I think using a touchscreen infotainment system such as the one demonstrated in the video could distract me while driving.	○	○	○	○	○
I think I would be able to access and use all functions of the touchscreen infotainment system demonstrated in the video.	○	○	○	○	○
I think using a touchscreen infotainment system such as the one demonstrated in the video would not require much effort.	○	○	○	○	○
I think I have the necessary knowledge and skills to use a touchscreen infotainment system such as the one demonstrated in the video.	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I think using a touchscreen infotainment system such as the one demonstrated in the video would not endanger my driving.	O	O	O	O	O
If I would have a touchscreen infotainment system such as the one demonstrated in the video in my car, I would connect my phone to it.	O	O	O	O	O
I think a touchscreen infotainment system such as the one demonstrated in the video would provide me with information that I can trust.	O	O	O	O	O
I think it would be pleasant to use a touchscreen infotainment system such as the one demonstrated in the video.	O	O	O	O	O
I would recommend a touchscreen infotainment system such as the one demonstrated in the video to my friends.	O	O	O	O	O

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I would feel comfortable if my child, spouse, parents, or other loved ones would use a touchscreen infotainment system such as the one demonstrated in the video.	○	○	○	○	○
I would recommend a touchscreen infotainment system such as the one demonstrated in the video to my child, spouse, parents or other loved ones.	○	○	○	○	○
People who are important to me would approve that I use a touchscreen infotainment system such as the one demonstrated in the video.	○	○	○	○	○
If a touchscreen infotainment system such as the one demonstrated in the video would be available in the market, I would intend to purchase such a system.	○	○	○	○	○
If my car would be equipped with a touchscreen infotainment system such as the one demonstrated in the video, I predict that I would use the system when driving.	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Assuming that a touchscreen infotainment system such as the one demonstrated in the video would be available, I would intend to use it regularly when driving.	O	O	O	O	O

How much would you be willing to pay for a touchscreen infotainment system such as the one demonstrated in the video if it would be an optional feature in a new car?

	< €200	€200 - €400	€401 - €600	€601- €850	€851 - €1000	€1001 - €1300	> €1300
Please indicate the answer option that best reflects your personal opinion.	O	O	O	O	O	O	O

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Appendix 3 : NASA-TLX

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High