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Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen

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In-Vehicle Infotainment System and driver distraction

Isabelle Roche Cerasi and Dagfinn Moe

Department of Mobility, SINTEF Community, Norway. E-mail: Isabelle.roche-cerasi@sintef.no

Ann-Helen Hansen and Bård Morten Johansen

Norwegian Council for Road Safety, Tullinsgate 2, Oslo, Norway.

This study examines the safety concerns related to the use of in-Vehicle Infotainment Systems and the implications for future road safety policy. A total of 44 students studying the driving instructor programme in Norway were asked to use four IVIS functions: to select a radio channel, change the car interior temperature, choose music on a streaming platform, and enter an address on the navigation system. They drove a car with double-pedal set on a specific route with a safety instructor on board. The rides were registered with eye-tracking glasses. Results show that vehicle touchscreen-based IVIS requires considerable attention and distracts drivers from the road and traffic situation. The NASA Raw Task Load Index and the evaluation of driver attention show that the navigation system led to longer and more fixations and increased the effort required to coordinate between brain, eyes and hands. The average total required time to solve the navigation task was 44 seconds, and of the 33 seconds of cumulative fixation time, drivers spent an average attention of 17 seconds on the road and traffic and 16 seconds on the touchscreen. A large share of drivers also spent a cumulative fixation time on the touchscreen over the NHTSA recommended threshold of 12 seconds. The longer the fixations are on the touchscreen, the more the traffic context may have changed. This work further discusses the risk incurred and the drivers' ability to react to risky situations, as well as the cognitive load associated with switching sequences between road and touchscreen.

Keywords: In-Vehicle Infotainment System, Driver distraction, Risk perception, Driver behaviour, Cognitive maps, Touchscreen,

1. Introduction

Cognitive maps are mental representations of the spatial environment, built by the place and grid cells of the brain, located in the hippocampus area and entorhinal cortex (Moser and Moser, 2017). These maps help us to understand where we are in the environment and how to navigate to another location. When significant changes occur in the environment, our cognitive maps are updated and replaced with new ones. In neuroscience, such changes are called "cognitive remapping" (Latuske, 2018; Green, 2022; Sugar, 2019). The brain continuously predicts and re-assesses, asking repeatedly, what is going to happen? where, when and how? (O`Keefe and Nadel, 1978; Buzsáki and Moser, 2013; Nadel, 2021). In-Vehicle Infotainment Systems (IVIS) are multimedia and navigation systems found with a pressure-sensitive screen in modern cars that users can use to enter inputs in systems. Previous studies have investigated driver-interaction with either IVIS or mobile phones, showing that using in-vehicle systems or devices requires high cognitive workload and time to interact with the system (Biondi et al., 2019; Buschholtz et al., 2023). Drivers switch attention between the traffic situation and the touchscreen.

According to the European Transport Safety Council, distraction greater from the road of 2 seconds or more double the risk of accident (ETSC, 2013). The National Highway Traffic Safety Administration published similar guidelines for evaluating eye gaze behaviour while driving, indicating that 85% of eye-glance durations away from the roadway should be ≤ 2 seconds. The attention cumulative time spent away from the roadway should be 12 seconds or less (NHTSA, 2013). In addition, The European New Car Assessment Programme (EuroNCAP) introduces a protocol for Driver Monitoring Systems (DMS), defining a long distraction as "a single long duration driver gaze away from the forward road between 3 and 4 seconds; and a short distraction driver gaze away for a cumulative 10 seconds within a 30 second time period, without returning to the road for a period long enough to be able to understand the road situation" (Euro NCAP, 2024). Advanced Driver Distraction Warning Systems mandated by the General Safety Regulation (2023) are also required to send warnings for eye glances away from the road that last more than 6 seconds when driving at 20 km/h to 50 km/h, and 3.5 seconds at 50 km/h or over (EU, 2023). In addition, the ISO 16673:2017 standard related to the "occlusion method to assess visual demand to the use of in-vehicle systems", requires that the secondary task should be done under 1.5 seconds and a Total Shutter Open Time (TSOT) of 12 seconds (vision not occluded) and Total Eyes-Off-Road Time (TEORT) of 9 seconds, considering that "0.5 second is spent transitioning the driver's eyes from the roadway to the object" (NHTSA, 2013).

More field tests are needed to evaluate the effects of using touchscreens when driving and the effectiveness of countermeasures addressing distraction (Tinga et al., 2023; Buchholtz et al., 2023).

2. Method

2.1. *Participants*

A total of 44 students from the 2-year Licence B Driving Instructor Education Program in Norway participated in the study. The gender distribution was 70 % men and 30 % women. They were 32 years old on average (SD = 9.5), with 50 % under 30 years old and with 73 % stating that they use the display system in their car daily and weekly. The ride took around 20-30 minutes.

2.2. *Procedure*

Participants had to drive a car with a 16/9 colour touchscreen and double pedal set and follow a defined route, where they had to perform four tasks on the touchscreen. Task 1 was to set the temperature for the driver and the passenger; Task 2, to select a song from an application; Task 3, to select a radio channel, and Task 4, to set an address in the navigation system. The route included urban roads with speed limits of 30–50 km/h and country roads with limit of 60–80 km/h.

A safety instructor in the passenger seat gave them the instructions at the right route locations. Safety had been emphasised by informing the drivers that after receiving the instructions, they could perform the requested tasks when they wanted, or even decide not to perform them. No time pressures were placed on them. A Tobii AB eye-tracking system registered driver and eye gaze behaviour during the ride with the safety instructor. Drivers' eye gaze alternated between saccades (20–40 ms), short glances between two places or objects, and fixations, meaning long looks at an object or place (100–600 ms) (Tobii AB, 2021).

Only the results for participants with high-quality gaze data sampling (over 90 %) have been analysed. The sampling rate was 50 Hz, but the natural reflex of blinking is often responsible for data loss of 5–10 %.

2.3. *Method*

Areas of interest are defined in the software to evaluate time spent looking away from the road and traffic (including interior and exterior mirrors) while drivers performed tasks on the 10-inch HD touchscreen. In addition, car speed was read from the vehicle instrument panel with the eye-tracking camera. Tasks were analysed during two referenced times, i.e., when the instructor started to give the instructions for the task and when the participant finished the task. After their ride, they also had to assess their driving by completing a 7 point-scale NASA-RTLX questionnaire.

2.4. *Research questions*

The main objective was to understand safety concerns related to the use of in-Vehicle Infotainment systems and implications for future road safety policy. The research questions are pursued:

RQ1: What are the drivers' visual and cognitive workload and driving performance while driving and using IVIS-touchscreen?

RQ2: How do drivers distribute their attention between the road and the touchscreen?

RQ3: What is the cumulative time spent when performing various tasks on the touchscreen?

RQ4: How does task performance on the touchscreen affect road safety and driving process?

3. Results

3.1. *Eye-tracking gaze*

Figure 1 shows the average cumulative times of the eye-tracking gaze samples, namely fixations and saccades for the drivers (with sampling rate over 90%) when performing the four tasks. The remaining samples are eye movements not found or not classified either as fixations or samples.

Results show that Task 1, setting the temperature for the driver and the passenger required the shortest average fixation time, 13.8 seconds (SD = 5.2), whereas Task 4, entering an address took the longest average time, 33.5 seconds (SD = 14.4). On average, drivers spent similar fixation times on the touchscreen for Tasks 2 and 3, at 23.5 seconds and 22.1 seconds respectively. Notably, the saccade times spent switching between locations also increased with fixation times.

The average total times spent performing the four tasks, including saccades, eye movements not found or not classified are: Task 1, Task 2, 30 seconds (SD = 12), 17 seconds (SD = 6), Task 3, 28 seconds (SD = 13), Task 4, 44 seconds (SD = 18).

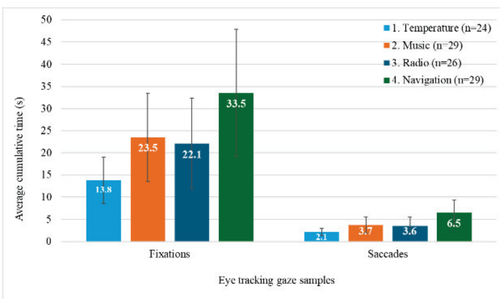

Fig. 1. Average cumulative times for eye-tracking gaze samples, from drivers performing the four tasks.

3.2. *Cumulative fixation time*

Figure 2 presents the average cumulative fixation times on road and traffic or touchscreen. The remaining locations are the instrument panel and the centre switch panel with average cumulative fixation times under 0.8 second. Task 1, setting the temperature, required the shortest average fixation time on the touchscreen, 3.4 seconds (SD = 1.4), whereas Task 4, entering an address took the longest average time, 15.7 seconds (SD = 7.3). On average, drivers spent similar cumulative times on the touchscreen for Tasks 2 and 3, 10.3 seconds and 11.2 seconds respectively. They also used comparable times on road and traffic, and touchscreen for three of the tasks (Music, Radio and Navigation).

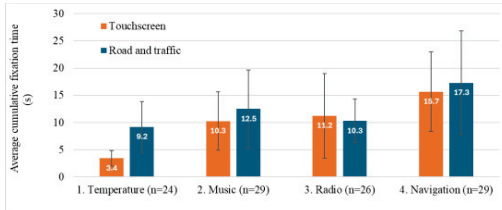

Fig. 2. Average cumulative fixation times when performing the four tasks.

Table 1 shows that all the drivers spent a cumulative time on the touchscreen under 12 seconds only when setting the temperature. Task 4, entering an address, had the largest share of drivers spending over 12 seconds on the touchscreen. The shares for Tasks 2 and 3 were 28 % and 35 % respectively.

Table 1. Number of drivers who spent a cumulative time > 12 seconds on touchscreen for the four tasks: Task 1, temperature (n = 24); Task 2, music (n = 29); Task 3, radio (n = 26); and Task 4, navigation (n = 29).

Cumulative time on touchscreen (s)	Task 1. N	%	Task 2. N	%	Task 3. N	%	Task 4. N	%
≤ 12 s	24	100	21	72	17	65	11	38
> 12 s	0	0	8	28	9	35	18	62
Total	24	100	29	100	26	100	29	100

3.3. *Number of fixations*

The average number of fixations spent either on road and traffic or touchscreen are presented in figure 3 below. Task 1 required, the lowest average number of fixations on the touchscreen, 11 points (SD = 3), whereas Task 4 required the greatest average number, 41 points (SD = 18). Tasks 2 and 3 are similar, on average at 31 points (SD = 17 and SD = 20). As for the cumulative fixation times, the average numbers of fixations are higher on road and traffic for Tasks 1. and 4.

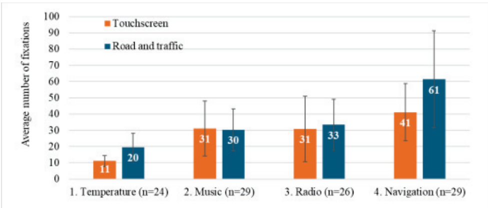

Fig. 3. Average number of fixations spent either on road and traffic or touchscreen.

In a comparison of the average fixation duration times on the touchscreen, Task 1 required the shortest time with 321 ms (SD = 136), and Task 4 with the longest time with 401 ms (SD = 134). The average cumulative fixation time spent on the touchscreen increases with the total average number of fixation points and the average fixation duration times.

3.4. *Eye-glance durations*

The drivers spent a total of 3162 fixation points on the touchscreen.

Table 2. Frequency of fixation durations when performing the four tasks: Task 1, temperature (n = 24), Task 2. music (n = 29), Task 3, radio (n = 26), and Task 4, navigation (n = 29).

Fixation durations (s)	Task 1 N	%	Task 2 N	%	Task 3 N	%	Task 4 N	%
0-0.5	225	84	723	80	603	75	892	75
0.5-0.99	40	15	155	17	160	20	225	19
1-1.5	1	0	24	3	28	3	52	4
1.5-1.99	1	0	2	0	8	1	14	1
≥ 2.0	0	0	0	0	2	0	7	1
Total	267	100	904	100	801	100	1190	100

Table 2 presents the frequency of fixation durations, showing that 75–85% of the fixation points on the touchscreen lasted less than 500ms. When the task is more demanding, the average duration time increases and the number of fixations over 2 seconds becomes the highest. The durations of more than 85% of fixations away from the roadway were ≤ to 2 seconds.

3.5. *Vehicle speed*

Drivers took the opportunity to spend more time on the touchscreen when the vehicle was stopped either at intersections or pedestrian crossings. However, the driving process is also affected, and drivers fall into a “mode” that deviates from the normal driving style.

Tasks were performed on roads with different speed limits. Task 1 was done on roads with a speed limit of 80 km/h, Task 2, 60 km/h, Task 3, 40 km/h and Task 4 on urban roads with a speed limit of 30 km/h. Figure 4 shows the scatter plot of the fixation durations on the touchscreen versus the vehicle speed indicated on the instrument panel.

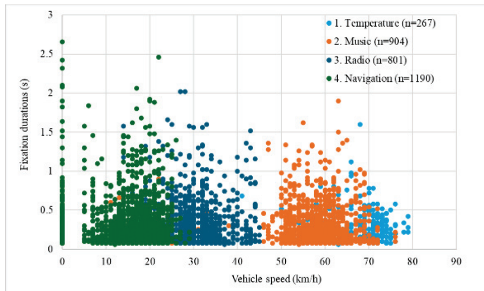

Fig. 4. Scatter plot of eye glance durations on the touchscreen versus the vehicle speed indicated on the instrument panel.

Figure 4 shows that among the nine fixations that lasted over 2 seconds, four eye glances were done at vehicle speeds between 17 and 28 km/h during Tasks 3 and 4. The fixation durations were not predicted by the vehicle speed. The scatter plots for the four tasks reflect more the characteristics of the tasks and the strategy of the drivers keeping most of their fixations under 500 ms.

3.6. *Attentional distribution*

Figure 5 presents an example of driver attentional distribution before and after instructions were given and when performing the navigation task. The speed limit of the zone where the driver performed the task is 30 km/h. Fixations on road and traffic are in blue, on the touchscreen in red, on the instrument panel on green, and on the centre switch panel in purple in figure 5 (above).

The vehicle speed values were taken from the instrument panel in the middle of each fixation (e.g., incremental values on figure 5, below). The driver stopped twice at a roundabout and in front of a pedestrian crossing (marked on figure 5 below).

The proposed example of the driver attentional distribution clearly reveals that the secondary task on the touchscreen (red colour) was considered by the driver as important as driving (blue colour) after the instructions were given. In general, drivers spent equal time on the road and the screen. Some drivers could use time when the vehicle was not moving, then focussing their attention on the centre switch panel to employ the manual buttons and touch functions of the screen, as shown in the example in figure 5.

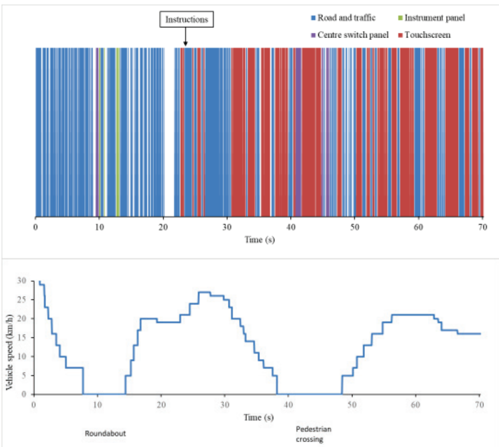

Fig. 5. Example of a driver attentional distribution before instructions and when performing the navigation task.

3.7. *NASA RTLX assessment tool*

Figure 6 shows the average attentional load perceived by the drivers for the four tasks. Task 1, setting the temperature for the driver and passenger (M = 2.6, SD = 1.1) was perceived as the least demanding task in terms of attentional load, whereas Task 4, entering an address in the navigation system (M = 4.4, SD = 1.5) was assessed as the most demanding task, with a score over the mean value. Drivers perceived similar attentional load for Tasks 2 (M = 4.0, SD = 1.4) and 3 (M = 3.8, SD = 1.3). The results spread from the mean scores, indicating differences in the perceived attentional load.

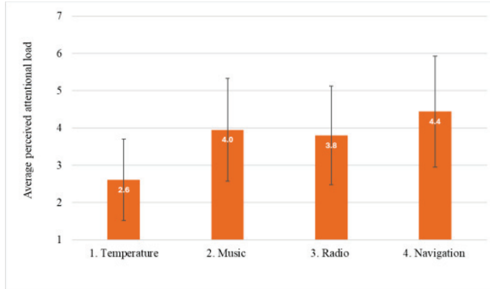

Fig. 6. Average attentional load perceived by the drivers for the four tasks (n=41).

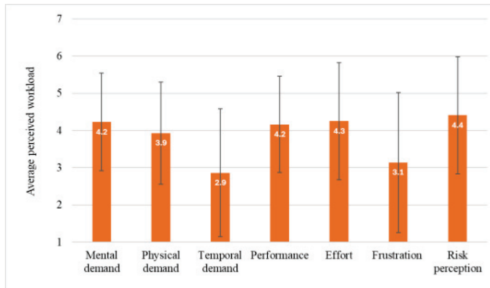

Fig. 7. Average workload and risk perceived by the drivers (n = 41).

Drivers were also asked after their ride to assess the workload on 7-point scales, divided into six subjective indicators: mental demand, physical demand, temporal demand, performance, and frustration level. In addition, they rated on the same scale, the risk to perform tasks on the touchscreen when driving.

Figure 7 presents the average scores of workload and risk perceived by the drivers. Drivers assessed mental demand (M = 4.2, SD = 1.3), task performance (M = 4.2, SD = 1.3) and own effort accomplished (M = 4.3, SD=1.6) above average, whereas the temporal demand (M = 2.9, SD = 1.7) and frustration level (M = 3.1, SD = 1.9) scores were perceived as low. Risk perceived by the drivers when performing the tasks was also above average (M = 4.4, SD = 1.6).

5. Discussion

This study examined visual and cognitive attention in the context of IVIS. It illuminates whether touchscreens might contribute to road accidents. Equipped with eye-tracking glasses, drivers performed four tasks (temperature, music, radio, and navigation) on the in-vehicle touchscreen. Results showed that the number of fixations and saccades increase with the workload required by the task. Task 4, entering an address in the navigation system was the most demanding task. For three of the tasks (music, radio, and navigation), a large share of drivers (28%, 35% and 62% respectively) spent a cumulative fixation time on the touchscreen over 12 seconds, the upper limit recommended by NHTSA (NHTSA, 2013). Blanco et al.'s study (2006) suggested that interacting with IVIS reduces attention and driving performance. Other previous studies have also found similar results, for example with drivers interacting with Android Auto and Apple CarPlay (Ramnath et al., 2020).

In the present study, we note drivers have a similar strategy, spending much time switching between the screen and the road. After having started a task, the common goal was to complete it. They all decided that it was safe to look away from the road and focus on the secondary task. However, they did not allot much more time on road than on screen when performing the four tasks. In case of unexpected situations, they would not have been able to adjust their behaviour (Strayer et al., 2017). In this study, the safety operator had to intervene a few times to prevent accidents (e.g., pedestrians crossing the road). Changes in driving style (i.e., slower speed) were also noticed for a few drivers both on urban roads and highways (as previously found by Platten et al., 2013).

Although technology designers do their best to develop simple functionalities requiring low cognitive workload and cumulative time, systems still demand too much visual attention and driver involvement (NHTSA, 2013). Touchscreens now have more and more applications, and digital technologies in cars are expected to increase. More standards and countermeasures are necessary to increase drivers' cautious regarding how long they look away from the road and from traffic.

Lachance-Tremblay et al. (2025) found that with auditory, tactile, and visual alerts, drivers used less time away from the roads. The challenge is to find the best criteria to trigger warnings and encourage a behaviour adapted to the situation.

Too many warnings could also end with drivers deactivating systems. Advanced Driver Assistance Systems (ADAS) (e.g., Forward Collision System and Lane Keeping Assistance) supporting the driving performance may also induce too much confidence in drivers causing them to spend more time on secondary tasks.

The present study helps clarify what safe eye glance behaviour might be during drivers' use of touchscreen use. Eye glance durations are not predicted by speed, though drivers used more time when stopped at intersections or pedestrian crossings. Furthermore, previous studies have recommended avoiding making available all the IVIS functions while driving (Ramnath et al., 2020). This may be part of the solution.

DMSs are also expected to contribute to road safety (Ledezma et al., 2021; Hayley et al., 2021; Masello et al., 2022). The eye glance duration criteria, according to the vehicle speed proposed by the General Safety Regulation of the European Commission (2023), may be explained by considering the implementation of automated systems and the desire to avoid many warnings during vehicle operation. More explorative research is currently evaluating the effectiveness of future DMSs on driver behaviour and road safety (Koniakowsky et al., 2025).

Previous studies have suggested that older and younger drivers have different visual distribution and perception in similar traffic situations. Future research should investigate the effects of various factors such as age, gender and education on driving performance when drivers use ADAS and a touchscreen. In addition to age, the factors of gender and education shape attitudes towards driving and the use of automated systems (Payre et al., 2014; Nordfjærn et al., 2010; Wu and Boyle, 2015). Chen et al. (2023) have found that driver characteristics influence their reaction, visual distribution, and mental workload. They proposed to develop tailor-made interfaces that are multimodal (i.e., visual, auditory and tactile). Complementary measures should also be considered, since systems may be unable to detect the eye movements of all drivers across situations. Such systems will also likely trigger false positive (triggered but not required) warnings, as well as false negative (required but not triggered). The reliability of warning systems is decisive for acceptance and adoption by drivers (Bliss and Acton, 2003).

Visual attention depends strongly on the context and the time necessary to understand the changes in the environment (Ahlström et al., 2022). Complex situations with various elements (e.g., vehicle, vulnerable road users, infrastructure) require more time. More research is necessary to understand whether time thresholds related to vehicle speeds provide sufficient safety. Research should be more coordinated, and databases should be created to follow the implementation of progressively advanced technologies in cars until we get to completely autonomous cars.

6. Conclusion

This research was based on eye-tracking data, aiming to improve knowledge of driver distraction when drivers use touchscreen-based IVIS. We performed naturalistic tests with drivers, asking them to execute four different tasks on the vehicle touchscreen at the same places on roads. This study clarifies the risks associated with the use of digital displays in modern cars. Results show that the average cumulative time drivers spent on the screen when performing the tasks, depended on the difficulty of the tasks. Task 1, setting the temperature demanded the least time, whereas Task 4, entering an address in the navigation system, generated on average the most fixations and cumulative screen time. The average total time to solve Task 4 was 44 seconds (SD = 18), and of the 33 seconds of fixation time, there were the same average attention spent on the road and touchscreen. A large share of drivers failed to complete the tasks under the time threshold of 12 seconds recommended by the NHTSA. The information revealed about attention shared between the road and the screen over short periods of time, at different vehicle speeds, and in various and complex traffic environments provides new knowledge for future behavioural research on highly automated vehicles with more tailormade and digital display systems in vehicles.

The study's limitations include that, even though it was conducted in real world traffic environments and the drivers were explicitly free to perform the tasks or not, the results may not reflect their own actual driving behaviour. For example, they may have felt obliged to successfully complete the tasks while driving.

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