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The effects of information relevancy on driving behavior

A simulator study on professional bus drivers

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Abstract

Bus driving is a complex and cognitively challenging task that places high demands on bus drivers' working memory. Increasing use of "In-Vehicle Information Systems" leads to driver distraction and is a contributing factor to many road accidents globally, and with systems for tickets, navigation, and timetables, bus drivers are more exposed to this additional workload than other actors in the traffic. This study provides insights into how bus drivers' driving behavior is affected by auditory traffic information through a driving simulator study at the Swedish National Road and Transport Research Institute. A prestudy showed that many bus drivers in Gothenburg experience that a majority of the messages they receive are irrelevant to them. Difference in driving behavior was identified for conditions in which the drivers received messages irrelevant to their route, which might indicate that irrelevancy is an important factor for the workload imposed to the drivers. We hypothesize that irrelevant messages require processing in the visuospatial sketchpad, which might increase workload more than just auditory information processing. The results of this study implies that the routines for traffic communication between traffic controllers and bus drivers should be considerate, as to reduce the number of irrelevant messages that are cognitively loading the bus drivers.

Keywords Working memory \cdot Cognitive workload \cdot Auditory secondary task \cdot Driving simulator \cdot Driver distraction \cdot Driving behavior

1 Introduction

Bus driving is a complex and cognitively demanding task that requires the ability to simultaneously process information from different sources. Driving a bus in city traffic places high demands on drivers' working memory (WM) which is constantly loaded from changes in dynamic traffic situations. More frequent use of In-Vehicle Information Systems (IVIS) poses an increased traffic hazard and many traffic accidents today can be attributed to distraction caused

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by these (Yang et al. 2010; Ranney et al. 2000). Both handheld and hands-free phone use can induce cognitive distraction (Recarte and Nunes 2003), and lead to an increased risk of missing traffic signals (Strayer et al. 2003), or adversely affect braking behavior (Treffner and Barrett 2004). Thus, hands-free phone use seems to occupy working memory capacity (Ross et al. 2014). Parnell et al. (2019) argues that the legislations seen in several countries against handheld phone use might create a false sense of security that makes it easy to justify one's hand-free phone use while driving. Strayer et al. (2019) argues that many IVIS features in commercial use today are in fact too distracting to be enabled while the vehicle is in motion.

Our WM capacity is limited (Proctor and Van Zandt 2008; Sweller 1988) and must suffice for both primary and secondary driving tasks in order not to be overloaded. Previous studies (Wood et al. 2016) have found connections between WM capacity and the ability to perform secondary tasks while driving. Studies have also found that drivers perform worse due to reduced attention on the primary driving

task during secondary auditory tasks (Chaparro et al. 2005), as well as cognitive (Ross et al. 2014), haptic (Kircher et al. 2014; Strand and Tegelid 2008) and visual tasks (Blanco et al. 2006).

At the time of writing, the traffic management in Gothenburg sends traffic information to all buses in circulation, regardless of who is affected by the information. A preliminary study by Mullaart and Nilsson (2017) at Västtrafik–the bus provider in Gothenburg showed that many drivers experience that of the majority of the received messages are irrelevant to them.

Given that all information communicated from the traffic controllers affects bus drivers performance negatively—even the irrelevant information—communication routines must be overlooked, and the number of messages heavily reduced, as to offload the drivers from unnecessary distractions sources. Present study seeks to reveal the impact of traffic messages on bus drivers, and to investigate the differences in induced cognitive workload between relevant and irrelevant traffic messages.

2 Working memory and driver distraction

It is important that the bus drivers' situational awareness, i.e. their perception and understanding of their environment, is constantly updated and consistent with the traffic situation. The creation and preservation of situational awareness is an active cognitive process involving the acquisition, updating, integration and retention of temporal and spatial information (Endsley 1995; Johannsdottir and Herdman 2010). The working memory capacity determines how high a degree of situational awareness can be achieved at any given time.

Working memory refers to the system that forms the basis of complex cognitive activity which requires the processing and preservation of information over short time spans. According to Baddeley (2015), the working memory mainly consists of four components that cooperates to process different types of information. The components are: the Central Executive, the Visuospatial Sketch pad, the Phonological Loop and the Episodic Buffer.

- The visuospatial sketch pad processes visuospatial information and is thus important for spatial orientation. In the visuospatial sketch pad, sensory information meets with stored information from the long-term memory, and the sketch pad links these elements together to create a coherent image.
- Just as the sketch pad treats and preserves visuospatial information, the phonological loop processes auditory information.

 The episodic buffer can be described as the link between working memory and long-term memory thus playing an important role for the other components work properly.

Wickens (1984) and Baddeley (1986) argue that working memory resources are divided into modalspecific pools. This means that depending on the modality used to solve a task, it is the resource type of that specific modality that will be used. If two separate tasks are performed simultaneously and rely on the same modality (e.g. visual), the working memory's capacity will be overloaded, leading to a reduced performance capability for one or both tasks. On the other hand, if the two separate tasks rely on different modalities (e.g. visual and auditory), the performance capability will only be affected if one or both tasks are so strenuous that they drain their respective resource pools (Wickens 1984). The task complexity also affects how much resources are required to solve it. However, repetition and training on difficult tasks can lead to a more resource efficient processing, and even lead to an automated behavior that can be performed without conscious awareness (Baddeley et al. 2015). In the bus drivers' work situation there are many factors that can induce high working memory load, but for experienced drivers, the load should be lower than for novices.

Vanderhaegen et al. (2019) highlights the role of attentional dissonances to disturbances in performance, and attributes them to consequences related to attentional failure. Attentional dissonance occurs when stimuli competes for attention with resulting cognitive conflicts.

The source of attentional dissonance is not always perceptional, but can also be triggered by emotional conflicts, higher-cognitive conflicts such as intent or objectives, or in-group conflicts between members of social constellations (Vanderhaegen et al. 2019). Hence, in the context of traffic safety, there are several potential conflicts that can induce attentional dissonance outside of the scope of present study, and the selection presented below are limited to those derived in conflicts of perception.

The tunnel effect is an attentional dissonance where cognitive resources are focused on particular stimuli to the extent that other information is neglected. The tunnel effect can occur during high levels of working memory load, or in situations where stress is experienced.

2.1 Related research

Research has shown that commuters' propensity for route switching proposed from radio traffic reports, RTR, and changeable message signs, CMS, is high, given that the proposed routes were known to the commuter and the correctness of the information was highly assessed (Jou et al. 2004). The same study reported that commuters' believed that the correctness and reliability of RTR and CMS, in general, was high, leading them to switch to the proposed routes. These results were partially confirmed in a study investigating attitudes towards CMS, that reported higher propensities towards CMS-evoked route shifting when the proposed route was familiar to the driver (Alkheder et al. 2019). However, this effect was only apparent when the CMS informed about congestion only, compared to when the CMS displayed accumulated information such as congestion, delay time, and suggestions of alternative routes.

Adhering to traffic information communicated from the traffic controllers is a natural part of the bus driving profession, as it is important for the general traffic flow that buses do not get stuck in congestion. Route switching is thus not optional for bus drivers and their propensity for it is ignored, something that might well induce insecurity if the suggested route is unfamiliar to the driver or if much information is presented simultaneously.

Since IVIS do not aim to facilitate a driver's primary task - to drive the vehicle safely-the use of such systems usually falls under the category of secondary tasks. However, secondary tasks while driving may also include other things, such as having a conversation with passengers (Shinohara et al. 2010; Sayer et al. 2007), processing auditory information (Chaparro et al. 2005) or perform motor actions such as regulating the temperature. Auditory information processing can adversely affect driving behavior (Chaparro et al. 2005), make the driver less aware of surrounding cars (Gugerty and Tirre 2000), lead to slower reaction times to traffic signs (Strayer et al. 2003) and give rise to inattentional blindness (Strayer and Johnston 2001). In an overview article on phone use during travel, Ishigami and Klein (2009) found that both handheld and hands-free phone use have a negative impact on driving behavior. In the studies they compared, it was found that the use of hands-free phone use rarely had a lesser impact on driving behavior compared to handheld. In some studies, it was also found that drivers compensated for the negative effects of handheld phone use, but not for hands-free. The authors argue that this indicates that hands-free phone use during travel can actually pose a bigger hazard than handheld. This view is in line with the findings of Eriksson, Kircher, Lindström and Sewald (2014). Listening to the radio while driving, however, does not adversely affect driving behavior in the same way as phone use does, which indicates that it is not only speech production that loads the working memory during a phone call. Drivers can, if the driving situation requires it, inhibit radio listening and focus their attention on the road instead (Strayer and Johnston 2001). Bus drivers who listen to a traffic message have the same choice, but the consequence of ignoring a traffic message is worse - the traffic message may contain information that can affect their driving route. Gherri and Eimer (2010) investigated whether active listening can affect visual attention while driving. Active listening is the process of fully concentrating on auditory information, for better comprehension and memorization. They found that active listening strongly affects visual attention, something contradicts previous consensus that visual attention is only affected by speech production Gherri and Eimer (2010). Thus, impaired driving behavior during phone conversations does not appear to be solely due to cognitively demanding processes such as verbal processing or speech production, but also by the assessed weighted importance of the messages. A study comparing the impact of phone conversations on driving behavior with passenger conversations found that telephone conversations affected driving behavior significantly more (Drews et al. 2009). This can be explained by the fact that the driver and the passenger have shared attention on the road (Gherri and Eimer 2010), and therefore, the rhythm of a conversation naturally adapts to the traffic situation. In telephone conversations, there is no shared attention as one party of the conversation does not have access to the traffic situation. Thus, the risk of auditory distraction increases in intensified traffic situations, in which the driver has to attend to the primary driving task. Two longitudinal parameters commonly used to measure driver distraction are speed, and distance to a lead vehicle. There is a clear and well-established correlation between speed and increased risk of accident (Papantoniou et al. 2017). Distracted drivers often apply compensatory strategies to regain control over a driving situation that is perceived as uncertain (Papantoniou et al. 2017). One such strategy is to lower the vehicle speed as to increase the available reaction time (Engström et al. 2005). In their review article, Papantoniou et al. (2017) also conclude that speed variation tends to increase during phone calls. The distance to a lead vehicle (headway) is regarded to be a good measure of how much safety distance the driver accepts (Papantoniou et al. 2017). One compensatory strategy for drivers who are distracted by phone calls is to increase the distance to the lead vehicle (Ranney et al. 2005; Strayer et al. 2003). Undistracted drivers correct the car's position with small and controlled steering wheel movements (Regan et al. 2008; Brooks et al. 2005). Distracted drivers, on the other hand, tend to correct the position of the car with large and long movements, and can make sudden movements if they find their lane position different from the desired position. This measure is called steering wheel reversal and can indicate cognitive load during distraction. Steering wheel reversals can be calculated in accordance with the instructions found in SAE (2015).

2.2 Purpose

This study seeks to investigate if and how bus drivers are affected by the relevancy of auditory traffic information. The purpose of this study is to contribute with insights that can lead to improvements in bus driver's work environment. Furthermore, the study's results can contribute to an increased understanding of how auditory information affects driving behavior. A change in driving behavior may indicate an elevation in working memory load (Engstrom et al. 2017), thus leaving the driver with less cognitive resources for more safety critical aspects of the traffic environment.

Previous research shows that artificial auditory secondary tasks can have detrimental effects on driving behavior (Chaparro et al. 2005). However, it is not known to which extent highly realistic auditory tasks such as listening to traffic messages during duty, affects the driving behavior of professional drivers, i.e. bus drivers. If the traffic messages that bus drivers are exposed to affects their ability to operate the bus safely, traffic management communication must be changed. This study aims to answer the following questions:

• RQ1: How is the driving behavior of professional bus drivers affected by highly realistic auditory traffic messages?

The communication system used by the bus operators in Gothenburg is designed such that all traffic messages are transmitted to every operating bus line even if the information does not affect them. Since the traffic messages potentially can affect their route they are compelled to listen and process the message until the relevancy of the message is understood. Therefore, building on RQ1, we also want to investigate whether the relevancy of messages (i.e. if the message affects the drivers route or not) has an additional impact on driving behavior. We therefore also want to answer the following question:

• RQ2: Is driving behavior affected by the relevancy of traffic messages?

3 Method

A simulator study with a repeated measures design was conducted at VTI, to compare the bus driver's driving behavior when exposed to relevant and irrelevant traffic messages. Four realistic traffic scenarios were created, which were described in 12 traffic messages. The content of the messages was based on real traffic messages that had been analyzed in a prior study. The traffic messages were recorded by a former traffic controller, for increased authenticity. Out of the 12 created traffic messages, half contained information that would be relevant to the bus line in the simulator



Fig. 1 Image of the Sim IV

and remaining messages contained irrelevant information. A traffic message lasted between 18–36 s.

3.1 Participants

Thirty professional bus drivers participated in the simulator study (26 men and 4 women)¹. The drivers' mean age was 48.8 years (SD = 11.1), and on average, they have had their bus driver's license for 14.5 years (SD = 11.7). Out of the participants, 11 were native Swedes, 18 had lived in Sweden for more than four years and 1 participant had lived in Sweden for two to four years. All participants received a compensation of SEK 1350. The study was conducted in compliance with the Helsinki ethical standards (World Medical Association 2013).

3.2 Material

The study was conducted in VTI's state of the art mobile platform driving simulator, Sim IV. The simulator has an advanced motion system that allows it to simulate longitudinal and lateral acceleration. The moving platform also generates vibrations to simulate different road surfaces and road qualities. For a more detailed description of Sim IV's specifications, see Jansson, et al. (2014). A Volvo truck cabin (model: FH16) was mounted on to the platform to better mimic the driving characteristics of a bus, as both the cabin and the software contains vehicle dynamics for a long (7.85 m), wide (2.4 m) and heavy (40 tons) vehicle.

¹ The gender distribution in the study corresponds to that found in the bus industry according to the Swedish Bus and Coach Federation (2019).



Fig. 2 Inside of the Volvo FH16 cabin during simulation

3.3 Dependent variables and operational definitions

The dependent variables used in the study were: longitudinal speed, steering wheel reversals and lateral position of the vehicle, which were collected at a frequency of 200 Hz. All operationalizations of dependent variables were based on recommendations found in SAE (2015) for vehicle-based measurements (Figs. 1, 2).

There is a clear and well-established correlation between longitudinal speed and accident risk (Manser and Hancock 2007). With increasing speed, the vehicle becomes more difficult to control and drivers must react more quickly to avoid dangerous situations. Distracted drivers often apply compensatory strategies to regain control of a driving situation that is perceived as unsafe Papantoniou et al. (2017). One such strategy is to slow down the vehicle to increase the available reaction time.

Undistracted drivers tend to frequently correct the position of the vehicle using small and controlled steering wheel movements (Brooks et al. 2005; Regan et al. 2008). Distracted drivers, on the other hand, tend to correct the position of the vehicle less frequently, using large and long movements, and can make sudden movements if they find their lane position deviating from their desired position. A decrease in steering wheel reversal rate while driving can thus indicate cognitive load during distraction Papantoniou et al. (2017). A steering wheel reversal was defined as a change in the steering wheel's direction. For a steering wheel reversal to count, it must occur in the opposite direction and at least 1°.

According to Engström et al. (2005) cognitive load induced by secondary tasks leads to a centering of the vehicle's lateral position. However, unlike visual and cognitive distractions, auditory distraction has been shown to

3.4 Measurement interval

To determine whether the independent variable relevancy affected driving behavior, a baseline run was created in which participants were not exposed to traffic messages. Since the road was identical for each lap, two positions were selected per lap where a message would be played, resulting in six positions in total. The positions were chosen based on (1) time between messages—they should not come too frequently, and (2) similar road characteristics—the curvature should be the same. Since the messages lasted between 18 and 36 s, driving behavior data was collected at 36 seconds at each measurement occasion.

3.5 Procedure

After having instructed the participants about the task at hand, a 3-min practice session was initiated on a straight road where participants were instructed to accelerate and decelerate to become familiarized with the driving dynamics of the bus. After the test run, participants had the opportunity to ask questions regarding the experiment and withdraw if they felt any discomfort before the experiment began.

Participants drove on a 30 km long rural road with traffic in both directions. The simulator drive consisted of 3×10 km road with the same curvature, lane width (3.25 m), inclination, speed limit (90 km/h) and weather conditions. To make sure the participants did not experience the road as unnatural and repetitive, the surrounding environment (e.g., type of vegetation and tree density) changed every lap. The weather was set to light fog to obstruct the visibility, but also to make it harder to recognize the recurring route.

A lead car was programmed to lie in front of the vehicle from 1100 m to the end of the drive, with a minimum distance between the vehicles of 75 m. It was programmed in such a way that it compensated for the driver's accelerations and decelerations, but delayed, as to not behave unnaturally.

4 Results

To investigate whether there was a difference in driving behavior during exposure between the created traffic messages, a one-way repeated measures ANOVA was performed in SPSS (2017) for each dependency measure.

4.1 Steering wheel reversal

One outlier was found according to a boxplot analysis. The steering wheel reversal was normally distributed as assessed by Shapiro-Wilk's test (p > 0.05). Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $x^2(2) = 1.401$, p > 0.05.

The steering wheel reversal differed between relevant messages (M = 26.83, F = 9.25), to irrelevant messages (M = 25.30, SD = 8.78) and baseline (M = 28.70, SD = 9.02). The relevancy of the traffic message led to a statistically significant difference in the steering wheel reversal, F (2, 58) = 10.012, p < 0.001, partial $\eta^2 = 0.257$. A pairwise comparison revealed a statistically significant difference in mean steering wheel reversals of irrelevant messages compared to baseline (M = 3.40, 95% CI [1.42, 5.37], p < 0.001).

4.2 Mean lateral position

No outliers were detected as assessed by a boxplot analysis. Standard deviation longitudinal velocity was normally distributed as assessed by Shapiro- Wilk's test (p > 0.05). Mean lateral position for relevant messages was (M = -1.77, SD = 0.12 m), for irrelevant messages (M = -1.79, SD = 0.14 m) and baseline (M = -1.76, SD = 0.11 m). Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, x^2 (2) = 5.400, p > 0.05. The relevance of the traffic message did not lead to any significant change in mean lateral position, F (2, 58) = 1.136, p > 0.05, partial $\eta^2 = 0.0103$.

4.3 Average longitudinal velocity

Ten outliers, five of which were extreme, were found through a boxplot analysis. Average longitudinal velocity was not normally distributed as assessed by Shapiro-Wilk's test (p < 0.05). Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, x^2 (2) = 5.714, p > 0.05. Average longitudinal velocity differed between relevant messages (M = 87.23, SD = 4.41 km/h), to irrelevant messages (M = 87.74, SD = 3.13 km/h) and baseline (M = 87.92, SD = 4.09 km/h). The relevancy of the traffic messages did not lead to any statistically significant change in average longitudinal velocity, F (2, 58) = 1.170, p > 0.05, partial $\eta^2 = 0.039$.

4.4 Standard deviation longitudinal velocity

No outliers were found according to a boxplot analysis. Standard deviation longitudinal velocity was normally distributed as assessed by Shapiro-Wilk's test (p > 0.05).

Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $x^2(2) = 1.565$, p > 0.05.

Standard deviation longitudinal velocity differed between relevant messages (M = 2.21 km/h), to irrelevant messages (M = 2.38 km/h) and baseline (M = 2.23 km/h). The relevancy of the traffic message did not lead to any statistically significant changes in standard deviation longitudinal velocity, F(2, 58) = 0.604, p > 0.05, partial $\eta^2 = 0.020$.

5 Discussion

The study objective was to investigate how driving behavior of professional bus drivers is affected by highly realistic auditory traffic messages. Changes in behavior when drivers are exposed to messages might indicate an increase in working memory load and constitute a safety hazard.

The research questions were:

- RQ1: How is the driving behavior of professional bus drivers affected by highly realistic auditory traffic messages?
- RQ2: Is driving behavior affected by the relevancy of traffic messages?

The statistical analysis revealed a significant decrease in the number of steering wheel reversals during exposure to irrelevant traffic messages compared to baseline. The analysis also showed that the average and standard deviation of longitudinal velocity did not differ significantly between the baseline level and message relevancy.

Previous research has shown that the processing of auditory information loads working memory in such a way that driving behavior suffers and situational awareness declines (Chaparro et al. 2005; Gugerty and Tirre 2000; Ishigami and Klein 2009). According to Wickens (1984), two tasks that rely on different modalities (e.g., visual and auditory) can affect each other's performance if one or both tasks are so exhausting that they drain their respective resource pools. The present study has not found support for this. If such an effect were detected, a significant difference between baseline and exposure to traffic messages would be revealed, regardless of the message relevancy. However, the results indicate that the relevancy of traffic messages in fact affects driving behavior. It is established that processing of auditory information in the phonological loop impairs working memory. Our results can be interpreted in the light of Baddeley's model of working memory and, more specifically, his theory of automated behavior (Baddeley et al. 2015). The drivers' average age was 48.8 years, and on average they have had a bus driver's license for 14.5 years. This indicates that they were experienced and thus skilled in operating vehicles similar to that used in the

study. We did not find that any longitudinal compensatory strategies were applied upon exposure, which indicates that participants' speed keeping is automated.

Automated speed keeping likely facilitates bus drivers in their everyday work as it relieves working memory load, which allows them to focus on other aspects of attention demanding traffic situations. However, automated speed keeping does not always have to be positive, for example, if it occurs in combination with increased working memory load. We found a significant difference in the number of steering wheel reversals upon exposure to irrelevant messages, compared to baseline driving. At the same time, we also found that measures of longitudinal velocity did not differ significantly.

Ishigami and Klein (2009) found that compensatory strategies, such as decreasing longitudinal velocity, were applied only when the drivers were aware of the elevated risk associated with a secondary task. In their study, the risk of using of a handheld phone while driving was perceived to be higher than that of a hands-free. Although the task of carrying out a conversation, regardless of the phone was being handheld or not, in fact equally affected their attentional resources. Instead it was the perceived elevated risk that motivated the compensatory strategy to be applied. Our results can be interpreted in the light of their findings. It might be the case that the bus drivers did not compensate the distraction, as assessed by the significant difference in steering wheel reversals, simply because listening to a traffic message is falsely perceived as a risk-free task.

It is important to note that speed keeping is an intentional process, whose status is updated as the driver samples the speedometer. The number of steering wheel reversals, on the other hand, is a measure of an unintentional act, whose status is difficult to overlook. The number of steering wheel reversals is thus a more sensitive indicator of working memory load than speed keeping. The results indicate that the drivers' working memory was strained above normal. It is conceivable that less experienced drivers, who have not yet attained abilities such as automated speed keeping, would have applied compensatory speed reduction strategies in similar situations.

The above framework can be extended if combined with theories of attentional dissonances. For example, tunneling effects can occur when workload levels are elevated or when stress is experienced (Vanderhaegen et al. 2019). Present study has found that workload was elevated when participants listened to traffic messages, and it is known that bus drivers often experience stress due to tight schedules, passenger responsibility and multiple IVIS to operate. Hence, there is a risk that the tunneling effect creates a trade-off between listening to potentially important traffic information, and focusing on the primary driving task. Why do irrelevant messages affect driving behavior more than relevant ones? A plausible explanation is that drivers inhibit irrelevant messages as to focus their attentional resources on their primary driving task. This cognitive process is demanding of working memory capacity, thus affecting driving behavior.

However, before the relevancy status of a message has been determined it can cause uncertainty regarding impact of the traffic situation on one's route, hence each message must be carefully evaluated. It is conceivable that this is done by visualizing one's own route, a process taking place in the visuospatial sketch pad. Similarly to the findings of Blanco et al. (2006) we believe that the drivers must compare the information given in the message with knowledge of his own route that is located in long-term memory, and then act accordingly. If the content of the message does not fit with the mental representation of the route, the message could be dismissed as irrelevant. However, in situations where the relevancy status is not clear a dissonance between one's information regarding the route and any new information from the traffic message can emerge. This will strain the working memory of the driver, and impose an increased risk for inattentional blindness.

This process includes all components of the working memory: the phonological loop processes auditory information, mental visualization takes place in the visuospatial sketch pad and the episodic buffer retrieves information from the long-term memory. As irrelevant information is processed, less resources are left for the processing of information related to the primary task. Since driving relies heavily on the visuospatial sketch pad, parallel processing in this system in particular should affect driving behavior.

6 Conclusions

Present study attempted to isolate the effects of one out of several secondary tasks that bus drivers carry out on a daily basis. Presenting the participants with a driving context of high ecological validity paved way for prerequisites needed to create an immersive scenario. This enabled the participants to engage with the presented task, without the distractions normally present during a work shift. A statistically significant difference in driving behavior was found in driving behavior between conditions, although only using a fraction of the sources of distracting elements normally present in the work environment of bus drivers. In reality, the complex aggregation of tasks that composes the bus drivers' work environment probably produce a multiplied amount of cognitive load than that represented in the present study.

The results indicate that irrelevant traffic messages strains working memory more than relevant messages. At the same time, bus drivers experience that they are exposed to more irrelevant traffic messages than relevant ones. For this reason, we believe that the traffic management should evaluate their routines for transmitting each traffic message to all bus lines. Instead, the messages should be directed only to the bus lines that are affected by the content.

Legislations have been accepted in several countries that prohibits drivers from using hand-held phones while driving (Parnell et al. 2019). Given this background, it is easy to understand why traffic management transmits the large amount of traffic messages seen, as the communication is consistently hands-free, and thus assessed safe. Present study shows the problem with exposing bus drivers to irrelevant traffic messages. We agree with Parnell et al. (2019) that the legislations against handheld phone use might induce a notion of false security, leading to the perception of hands-free phone use being a safe alternative to verbal communication while driving.

7 Future research

We believe that the cognitive load occurs when irrelevant message content is integrated with prior knowledge, i.e. the process where the following questions are answered: "How does the message information affect my route and what should I do to avoid the obstacle?" It would therefore be interesting to investigate how working memory is affected by a visualization task while driving. Such a study would shed light on the phenomenon we believe to have identified.

We are also interested in investigating how long bus drivers remember traffic messages. This is interesting because the distance to the obstacle that the traffic message informs about determines how long drivers have to keep the information in their short-term memory. The severity of this memorization task should correlate with the amount of information to remember.

It would be of interest to carry out a naturalistic study that examines how bus drivers are affected by traffic messages with other distraction sources present, for example from IVIS and passengers. This could provide an explanation to whether auditory information processing gives rise to altered driving behavior at high working memory loads.

Above studies could be conducted through a synthesis between quantitative and qualitative data gathering methods. For example, eye-tracking data could reveal gaze behaviour and heart rates be connected to the effects of secondary stimuli. Qualitative data such as NASA-TLX could be used to evaluate the participants subjective workload during the experiments, thus providing a nuanced perspective on the effect of auditory traffic messages. Acknowledgements Open access funding provided by Swedish National Road and Transport Research Institute (VTI). We would like to express our deepest gratitude to Alexander Almér and Nataliya Berbyuk Lindström for their useful comments of this research work. We would also like to thank Bruno Augusto, Research Engineer at VTI, for providing us with technical expertise. We would like to acknowledge VTI for contributing with the simulator used in the study. Additional thanks to Västtrafik and Keolis for providing us with the bus drivers that participated in the study.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

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References

- Alkheder S, Alrukaibi F, Aiash A (2019) Drivers' response to variable message signs (vms) in Kuwait. Cognit Technol Work. https://doi. org/10.1007/s10111-019-00538-7
- Baddeley A (1986) Working memory. Oxford psychology series. Clarendon Press, Oxford
- Baddeley A, Eysenck M, Anderson M (2015) Memory. Taylor & Francis, Oxford
- Blanco M, Biever W, Gallagher J, Dingus T (2006) The impact of secondary task cognitive processing demand on driving performance. Accid. Anal. Prev. 38:895–906. https://doi. org/10.1016/j.aap.2006.02.015
- Brooks JO, Tyrrell RA, Frank TA (2005) The effects of severe visual challenges on steering performance in visually healthy young drivers. Optom Vis Sci 82(8):689–97
- Caird J, Willness C, Steel P, Scialfa C (2008) A meta-analysis of the effects of cell phones on driver performance [electronic version]. Acc Anal Prev 40:1282–93. https://doi.org/10.1016/j. aap.2008.01.009
- Chaparro A, Wood J, Carberry T (2005) Effects of age and auditory and visual dual-tasks on closed road driving performance. Optom Vis Sci 82:747–54. https://doi.org/10.1097/01. opx.0000174724.74957.45
- Drews F, Pasupathi M, Strayer D (2009) Passenger and cell phone conversations in simulated driving. J Exp Psychol Appl 14:392– 400. https://doi.org/10.1037/a0013119
- Endsley M (1995) Toward a theory of situation awareness in dynamic systems. Hum Fact 37:32–64. https://doi.org/10.1518/00187 2095779049543
- Engström J, Johansson E, Östlund J (2005) Effects of visual and cognitive load in simulated motorway driving. Transportation Research Part F: Traffic Psychology and Behaviour 8:97–120. https://doi.org/10.1016/j.trf.2005.04.012

- Engstrom J, Markkula G, Victor T, Merat N (2017) Effects of cognitive load on driving performance: the cognitive control hypothesis. Hum Fact. https://doi.org/10.1177/0018720817690639
- Gherri E, Eimer M (2010) Active listening impairs visual perception and selectivity: an erp study of auditory dual-task costs on visual attention. J Cogn Neurosci 23:832–44. https://doi. org/10.1162/jocn.2010.21468
- Gugerty L, Tirre W (2000) Individual differences in situation awareness. In: Situational awareness analysis and measurement, pp 249–276
- Horrey W, Wickens C (2006) Examining the impact of cell phone conversations on driving using meta-analytic techniques. Hum Fact 48:196–205. https://doi.org/10.1518/001872006776412135
- IBM Corp (2017) IBM SPSS Statistics for Windows, Version 25.0. IBM Corp
- Ishigami Y, Klein R (2009) Is a hands-free phone safer than a handheld phone? J Saf Res 40:157–64. https://doi.org/10.1016/j. jsr.2009.02.006
- Jansson J, Sandin J, Augusto B, Fischer M, Blissing B, Källgren L (2014) Design and performance of the vti sim iv, Driving Simulation Conference, Paris, France, 2014. Paris: Driving Simulation Association
- Johannsdottir K, Herdman C (2010) The role of working memory in supporting drivers' situation awareness for surrounding traffic. Hum Fact 52:663–73. https://doi.org/10.1177/0018720810 385427
- Jou R, Lam S, Weng M, Chen C (2004) Real time traffic information and its impacts on route switching behavior of expressway drivers. J Adv Transp 38:187–223
- Kircher K, Ahlström C, Rydström A, Aust ML, Ricknaas D, Almgren S, Naabo A (2014) Secondary task workload test bench: 2tb. Swedish National Road and Transport Research Institute. https ://www.diva-portal.org/smash/get/diva2:714215/FULLTEXT01 .pdf
- Manser M, Hancock P (2007) The influence of perceptual speed regulation on speed perception, choice, and control: tunnel wall characteristics and influences. Acc Anal Prev 39(1):69–78
- Mullaart M, Nilsson H (2017) Bus drivers working environment. Unpublished manuscript
- Papantoniou P, Papadimitriou E, Yannis G (2017) Review of driving performance parameters critical for distracted driving research. Transp Res Procedia 25:1801–1810. https://doi.org/10.1016/j. trpro.2017.05.148
- Parnell KJ, Stanton NA, Plant KL (2019) Driver distraction: a sociotechnical systems approach. CRC PRess, Taylor & Francis Group, Boca Raton
- Proctor R, Van Zandt T (2008) Human factors in simple and complex systems, 2nd edn. CRC Press, Boca Raton
- Ranney T, Mazzae E, Garrott W, Goodman M (2000) NHTSA driver distraction research: past present and future. National Highway Traffic Safety Administration, Washington D.C
- Ranney T, Harbluk J, Noy I (2005) Effects of voice technology on test track driving performance: implications for driver distraction. Hum Fact 47(2):439–454. https://doi.org/10.1518/00187 20054679515
- Recarte M, Nunes L (2003) Mental workload while driving: Effects on visual search, discrimination, and decision making. J Exp Psychol Appl 9:119–37. https://doi.org/10.1037/1076-898X.9.2.119
- Regan M, Lee M, Young J (2008) Driver distraction: theory, effects and mitigation. CRC Press, Boca Raton

- Ross V, Jongen E, Wang W, Brijs T, Brijs K, Ruiter R, Wets G (2014) Investigating the influence of working memory capacity when driving behavior is combined with cognitive load: an lct study of young novice drivers. Accid Anal Prev. https://doi.org/10.1016/j. aap.2013.06.032
- SAE (2015) SAE J 2944:2015: Operational definitions of driving performance measures and statistics. SAE International. https://www. sae.org/standards/content/j2944_201506/
- Sayer J, Devonshire J, Flannagan C (2007) Naturalistic driving performance during secondary tasks. Proceedings of the 4th International driving symposium on human factors in driver assessment, training, and vehicle design. Iowa: Driving Assessment Conference
- Shinohara K, Nakamura T, Tatsuta S, Iba Y (2010) Detailed analysis of distraction induced by in-vehicle verbal interactions on visual search performance. IATSS Res 34:42–47. https://doi. org/10.1016/j.iatssr.2010.06.004
- Strand N, Tegelid A (2008) Effekten av visuell och kompletterande haptisk feedback påföraren i ett fordonsgränssnitt. https://doi. org/10.13140/RG.2.2.26385.33123
- Strayer D, Johnston W (2001) Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. Psychol Sci 12:462–6. https://doi.org/10.1111/1467-9280.00386
- Strayer D, Drews F, Johnston W (2003) Cell phone-induced failures of visual attention during simulated driving. J Exp Psychol Appl 9:23–32. https://doi.org/10.1037/1076-898X.9.1.23
- Strayer D, Cooper J, Goethe R, McCarty M, Getty D, Biondi F (2019) Assessing the visual and cognitive demands of in-vehicle. Inf Syst. https://doi.org/10.6084/m9.figshare.c.4551593
- Swedish Bus and Coach Federation (2019) Swedish: statistik om bussbranschen. Sveriges Bussföretag, Stockholm. https://www.trans portforetagen.se/globalassets/rapporter/buss/190827-statistikr apport2019final.pdf?ts=8d79ff6569b3d00
- Sweller J (1988) Cognitive load during problem solving: effects on learning. Cognit Sci 12:257–285
- Treffner PJ, Barrett R (2004) Hands-free mobile phone speech while driving degrades coordination and control. Transp Res Part F Traffic Psychol Behav. https://doi.org/10.1016/j.trf.2004.09.002.
- Vanderhaegen F, Wolff M, Mollard R (2019) Synchronization of stimuli with heart rate: a new challenge to control attentional dissonances, chap 1. Wiley, Oxford, pp 1–28
- Wickens C (1984) Processing resources and attention, varieties of attention. Academic Press, New York
- Wood G, Hartley G, Furley P, Wilson M (2016) Working memory capacity, visual attention and hazard perception in driving. J Appl Res Mem Cognit. https://doi.org/10.1016/j.jarmac.2016.04.009
- World Medical Association (2013) World medical association declaration of helsinki: ethical principles for medical research involving human subjects. JAMA 310(20):2191–2194
- Yang Y, McDonald M, Zheng P (2010) The effects of increasing workload on drivers' eye movement. In: Proceedings of the 12th WCTR conference, vol 1, pp 1–12

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