

The impact of interface modality on police officers' visual behaviour when using an in-vehicle system

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Abstract

Background: Standard operating procedures state that police officers should not drive while interacting with their mobile data terminal (MDT) which provides in-vehicle information essential to police work. Such interactions do however occur in practice and represent a potential source of driver distraction. The MDT comprises visual output with manual input via touch screen and keyboard. This study investigated the potential for alternative input and output methods to mitigate driver distraction with specific focus on eye movements.

Method: Nineteen experienced drivers of police vehicles (one female) from the NSW Police Force completed four simulated urban drives. Three drives included a concurrent secondary task: imitation licence plate search using an emulated MDT. Three different interface methods were examined: Visual-Manual, Visual-Voice, and Audio-Voice ("Visual" and "Audio" = output modality; "Manual" and "Voice" = input modality). During each drive, eye movements were recorded using FaceLAB™ (Seeing Machines Ltd, Canberra, ACT). Gaze direction and glances on the MDT were assessed.

Results: The Visual-Voice and Visual-Manual interfaces resulted in a significantly greater number of glances towards the MDT than Audio-Voice or Baseline. The Visual-Manual and Visual-Voice interfaces resulted in significantly more glances to the display than Audio-Voice or Baseline. For longer duration glances (>2s and 1-2s) the Visual-Manual interface resulted in significantly more fixations than Baseline or Audio-Voice. The short duration glances (<1s) were significantly greater for both Visual-Voice and Visual-Manual compared with Baseline and Audio-Voice. There were no significant differences between Baseline and Audio-Voice.

Conclusion: An Audio-Voice interface has the greatest potential to decrease visual distraction to police drivers. However, it is acknowledged that an audio output may have limitations for information presentation compared with visual output. The Visual-Voice interface offers an environment where the capacity to present information is sustained, whilst distraction to the driver is reduced (compared to Visual-Manual) by enabling adaptation of fixation behaviour.

Introduction

Driver distraction can be defined as a diversion of attention away from activities critical for safe driving, towards a competing activity (Lee et al. 2008). In-vehicle information systems (IVIS) are well-recognised as having the potential to distract drivers. As such, driver distraction due to IVIS is widely investigated (for a review see Horrey 2011). Interaction with IVIS impairs vehicle control and reduces reaction time to hazardous events (e.g. Kaber et al. 2012, Owens et al. 2011 Maciej and Vollrath 2009, Young et al. 2012, Mitsopoulos-Rubens et al. 2011). Interacting with IVIS while driving requires a division of attention; consequently, multiple tasks may be competing for the same resource, resulting in degradation of performance in one or more of them (Liang et al. 2012).

One of the key concerns regarding distracted drivers is the proportion of time spent not looking at the road ahead. A common crash/near crash situation involves an unexpected event occurring in the road environment at a time when the driver is not looking in the appropriate direction (Dingus and Klauer 2008). As such, guidelines for good IVIS design include recommendations for the number and duration of glances

required to complete any given task (e.g. AAM, 2002; ISO, 2006; SAE, 2000). A principal recommendation is that glances required to complete a task should not exceed two seconds and that the task should be easily interruptible. A self-paced easily interruptible task allows a driver to divide their attention intelligently between the IVIS and the road environment (Jamson et al 2004). When comparing a fixed-pace and self-paced interruptible secondary task, self-regulating behaviour becomes apparent with drivers adapting their glance behaviour according to the demands of the driving task (Metz et al. 2011).

The safety critical glance duration appears to be around two seconds as in-vehicle glances of >2 s are linked to increased risk of crash/near crash (Dingus and Klauer 2008, Klauer et al. 2006). Additionally, it has been found that removing drivers' attention from the forward road way for a period of 2 s impairs vehicle control (Ryu et al. 2013). Driving by its nature, requires glances away from the forward road; however, the average necessary glance time taken to complete a routine safety task, such as checking the odometer (0.98 s) and checking the rear-view mirror (1.63 s), is shorter than the 2 s safety critical value (Sodhi et al. 2002). The number of longer, safety critical (>2 s) glances towards an in-vehicle technology increases with heightened visual complexity of the secondary task, as well as varying due to how interruptible the task is (Victor et al. 2005, Chiang et al. 2004). Mean glance duration to complete a particular secondary task (e.g. GPS navigation) is highly consistent between participants. In general, if one keystroke is required mean glance duration will be 1.0 s, increasing to 1.5 s if two keystrokes are required. This is so consistent that 94% of glances towards the display when 1 or 2 keystrokes were required are completed in less than 2 s (Chiang et al. 2004). Unsafe conditions are characteristically the exception and not the norm. Crashes tend not to occur under "typical" conditions, consequently analyzing only mean glance duration may result in biased conclusions (Horrey and Wickens, 2007). As such, when evaluating the potential for a secondary task to distract a driver it is most valuable to investigate the number and duration of long (atypical) glances (Horrey and Wickens, 2007).

One factor which may influence glance duration when completing an in-vehicle secondary task is the modality of the interface. In particular, in-vehicle technologies featuring Voice input capabilities have potential for decreasing the duration of glances away from the road and thereby alleviating some of the experienced driving impairment (Maciej and Vollrath 2009, Ranney et al. 2005). This is confirmed by naturalistic observation, reporting that Audio-Voice tasks are less risky and result in reduced eyes off the road time than equivalent Visual-Manual secondary tasks completed whilst driving (Dingus and Klauer 2008). However, it should be noted that even with a voice-based interface driving performance remains impaired compared to baseline (Maciej and Vollrath 2009).

Despite the potential negative effects of IVIS interaction on driving performance, there are some situations in which it is necessary to install complex technology in a vehicle passenger compartment; one example is police vehicles. Modern police vehicles contain much technology that is necessary for police work, this includes the MDT which provides officers with access to police relevant information in a timely manner. Since the introduction of MDTs the productivity of police work has greatly improved (Hampton and Langham 2005).

Typically, the MDT comprises a visual display (Visual output) with touch screen capabilities (Manual input), mounted high on the centre console of the vehicle.

Although the MDT display usually has touch screen capabilities, observation studies of actual use in police vehicles have noted that an independent keyboard is often used in conjunction with the MDT display touch screen (Hampton and Langham 2005, McKinnon et al. 2011). Using the MDT has become so central to modern policing that it is the most common in-vehicle activity undertaken by drivers of police vehicles (McKinnon et al. 2011). Although police drivers are advised not to use the MDT while the vehicle is in motion, in practice such interaction does occur (Hampton and Langham 2005). The potential for driver distraction is at its greatest in those situations when the driver is the only police officer in the vehicle, however, there is a lack of research into police vehicle driver distraction. A common example of a task using the MDT is to search a police database for a licence plate number, while maintaining visual contact with the vehicle being checked (Marcus and Gasperini 2006). Interaction with the MDT has strong potential to distract the driver through manual interaction in a single operator setting. In fact, 22.3% of police driving time is spent with a single arm controlling the steering wheel, although this proportion is not solely attributed to MDT interaction (McKinnon et al. 2011). Although in-vehicle voice command technology is commercially available, it is not readily utilised within police vehicles in Australia at this time.

It is apparent from published research that IVIS have strong potential to distract drivers; in particular, giving rise to long glances towards an IVIS which are safety critical. In-vehicle technology is necessary for efficient police work; however, driver interactions with the MDT may have implications for driver glance patterns and subsequently, road safety. One aspect with the ability to alleviate at least some of the potential for driver distraction is interface modality. In this study we examined eye glance behavior of experienced police vehicle drivers when interaction with various combination of MDT input/output. Three interface methods were investigated using a driving simulator protocol with police vehicle drivers; (1) Visual-Manual, (2) Visual-Voice and (3) Audio-Voice. The current paper reports on the implications for glance patterns towards the display screen, with safety critical glances (>2 s) being of particular interest. The implications for driving performance, secondary task performance and subjective workload are reported elsewhere (e.g., Mitsopoulos-Rubens et al 2013).

Method

Participants

Nineteen experienced drivers of police vehicles (18 males; 1 female) mean age 47.2 years (SD 6.8) were recruited from the New South Wales (NSW) Police Driver Training unit. All participants underwent screening procedures to ensure that they regularly drove police vehicles and met the local legal driving criterion of visual acuity for driving (normal or corrected-to-normal vision). Participants had worked for the NSW Police Force for at least five years (Mean = 18.0 years; SD = 8.4 years), and reported spending an average of 20.7 hours (SD = 9.2) each week in a police vehicle. All participants provided informed consent and the study was approved by the Monash University Human Ethics Committee.

Equipment

Driving simulator

The MUARC mid-range driving simulator, which consists of a full-size Holden sedan on a fixed-base, was used. Participants were able to control the throttle, brakes, steering and in-vehicle controls (indicators, headlights etc). The simulated scenario was displayed on a curved projection screen providing a 180° horizontal and 40° vertical field-of-view with an additional screen for the rearward view. A digital speedometer was presented on the instrument panel, to allow participants to monitor their speed.

Scenario

The MUARC Driver Distraction Test (Young et al. 2009) was used in the current study. In each test drive, participants were presented with an urban road scenario spanning approximately 6.6 kilometres and taking approximately 10 minutes to complete. The road was straight and undivided. Participants were instructed to drive as they normally would (on the left side of the road), taking into consideration the speed limit and other road users. Throughout the drive participants were required to stay in the left lane, unless directed by signs to change lanes or turn. On-coming traffic was presented at pre-determined intervals.

Eye tracking

Visual scanning of the road and speedometer was recorded using FaceLAB™ (Seeing Machines Ltd, Canberra, ACT). The system comprised two unobtrusive stereo cameras set on an adjustable mounting plate fixed to the dash board. Infrared illumination facilitated pupil and head movement tracking in three dimensions at a rate of 60Hz, with a static accuracy of gaze direction measurement within +/- 5° rotational error (Classic configuration). The eye tracker was calibrated for each participant at the start of each session.

Secondary task

Participants were required to perform a police-relevant secondary task concurrently while driving. This task required participants to search for a licence plate number in a simulated police database. In each case, a stimulus was presented by the system, memorised by the participant, re-entered into the system by the participant, and an outcome presented (i.e. "Match" or "No match"). The stimuli comprised two letters, two numbers and two letters (e.g. BM48RP). This configuration matches the licence plate number structure being implemented in NSW at the time of the study. Participants were instructed to respond as quickly as they felt they needed to, but not so quickly that they made errors. Stimuli were presented randomly from a list of 60 items. Once an item was completed there was a delay of 10 seconds before the next stimulus was presented. Accuracy was recorded as the percentage of secondary tasks attempted where the licence plate number entered by the participant matched the stimulus presented.

This task was completed using three different interface types: Visual-Manual, Visual-Voice and Audio-Voice. The Visual-Manual interface was the scenario most like the current MDT used in police vehicles. In this case the stimuli were presented on a Visual display screen positioned on the centre console (Figure 1) and input was Manual using a keyboard and touch screen display. The outcome was then presented on the screen. The Visual-Voice interface presented the stimuli using the same display screen

as the Visual-Manual interface. In this instance input was by Voice, with participants dictating each character of a stimulus into a headset-mounted microphone. The outcome of the simulated search was then displayed on the screen. The final interface used an Audio output whereby participants heard the stimuli through the headphone of their head set. Participants were then required to input their response by Voice in the same manner as the Visual-Voice option. The outcome was then relayed through the headset. In every case, the task was programmed and run using DirectRT v2012 experimental psychology software (Empirisoft Corporation). To replicate the operational noise environment of a police vehicle a recording of a real police radio broadcast was played throughout each drive. Additionally, the simulated scenario included appropriate sound (i.e. engine noise, noise of passing traffic etc).

[Insert Figure 1 here – portrait]

Figure 1 Location of the visual display in the simulator vehicle

To ensure that the outcomes of the three task versions were comparable an emulated speech recognition technique was used. This involved manual input of each response by an experimenter unknown to the participant.

Procedure

All participants completed a background demographics questionnaire and then underwent training and practiced driving the simulator and completing each version of the secondary task. Once participants were proficient at both simulator driving and secondary task completion, four experimental trials were completed. The complete experimental session lasted approximately 90 minutes per participant. The four experimental conditions included a Baseline (no secondary task) and one trial with each of the interface options: Visual-Manual, Visual-Voice and Audio-Voice. The order of the four conditions was counterbalanced between participants. In the three conditions where the secondary task was completed concurrently with driving, participants were instructed to prioritise the driving component.

Measures

The dependent variables of interest are the eye tracking outcomes: percentage of total gaze time on the road, percentage of total gaze time on the display screen, number of glances towards the display screen, the mean number of glances per completed task, mean glance duration and glance duration distribution (<1s, 1 – 2s and >2s). Gaze at the forward road scene was considered to be within ± 10 degrees in the horizontal plane and ± 5 degrees in the vertical plane, from the centre of the road. Gaze on the display was considered as an area 10 degrees (horizontal) by 10 degrees (vertical). The centre point of the gaze on the display was realigned appropriately for each participant.

Statistical analysis

All statistical analyses were conducted using PASW 20.0 statistical software. An alpha level of .05 was used to determine statistical significance. Proportion of gaze time towards the forward road and display screen was analysed using repeated measures ANOVA with the within-subjects factor of trial condition (4 levels: baseline, Visual-

Manual, Visual-Voice and Audio-Voice). Post hoc pairwise comparisons were conducted by paired t-test using Bonferroni adjustment ($p \leq 0.008$).

The total count-based eye movement data were analysed using Generalised Estimating Equations (GEE; Liang and Zeger 1986). A glance was defined as an uninterrupted fixation to a region of interest minus saccade transition time. In the current study, the region of interest was the visual display. The inter-correlation matrix was specified as unstructured. The GEE was specified with Poisson distribution and log link function. The only effect estimated was a condition main effect. The change in distribution of glance duration towards the display (<1 s, $1-2$ s and >2 s) is reported for each interface. Glances >2 s were considered to be safety critical, in-line with findings from previous research. (Klauer et al. 2006, Dingus and Klauer 2008, Victor et al. 2005, Ryu et al. 2013).

Results

The FaceLAB system could not be calibrated for three participants. Thus, eye movement data are presented for 16 participants only. The implications for driving performance, secondary task accuracy and subjective workload are reported elsewhere (e.g., Mitsopoulos-Rubens et al. 2013). Participant's demonstrated significantly greater accuracy at secondary task during the Visual-Voice condition (72.1%) than during either the Audio-Voice (54.1%) or the Visual-Manual (59.2%) conditions.

Proportion of gaze time on the road and on the display screen

There was a significant main effect of condition for both the mean proportion of gaze time on the forward road scene ($F(3,45) = 7.60, p < 0.001$), and towards the visual display ($F(2,29) = 11.75, p < 0.001$). Figure 2 demonstrates the proportion of gaze time on the forward road scene. Post hoc analysis revealed that a significantly greater proportion of time was spent looking at the forward road scene during both the Visual-Voice and Audio-Voice conditions compared to the Visual-Manual condition ($p \leq 0.008$).

[Insert Figure 2 here – portrait]

Figure 2 Mean percentage of time with eyes on the forward road scene (error bars represent standard error. BL = Baseline, VM = Visual-Manual, VV = Visual-Voice, AV = Audio-Voice)

Figure 3 displays the proportion of gaze time towards the emulated MDT display screen. Post hoc analysis identified significantly more time spent looking at the screen during the Visual-Manual condition than during either the Audio-Visual condition or Baseline. Similarly, a greater proportion of gaze time was spent on the display screen during the Visual-Voice condition than either the Audio-Voice condition or Baseline. There was no significant difference between either visual output conditions (Visual-Voice and Visual-Manual) or between Audio-Voice and Baseline.

[Insert Figure 3 here – portrait]

Figure 3 Mean percentage of time with eyes on the display (error bars represent standard error. BL = Baseline, VM = Visual-Manual, VV = Visual-Voice, AV = Audio-Voice)

Glance characteristics

Figure 4 displays the gaze characteristics under the three conditions. There was a significant effect of condition on mean glance duration towards the emulated MDT ($F(2, 30) = 3.528, p < .05$). Post hoc analysis identified mean glance duration to be significantly longer during the Visual-Manual than Visual-Voice condition. Similarly, there was a significant effect of condition on mean number of glances towards the emulated MDT per task completed ($F(2, 30) = 12.242, p < .001$). Post hoc analysis identified that significantly fewer glances per task occurred during the Audio-Voice condition than during either Visual-Manual or Visual-Voice.

[Insert Figure 4 here – portrait]

Figure 4 Glance characteristics. Mean glance duration on the display (left) and mean number of glances per task completed (right) (error bars represent standard error. VM = Visual-Manual, VV = Visual-Voice, AV = Audio-Voice)

Proportion of glances on the visual display

The average number of glances made towards the display during the entirety of each drive was 64 during Baseline, 347 using the Visual-Manual interface, 412 using the Visual-Voice interface and 73 using the Audio-Voice interface. GEE revealed there to be a significant main effect of condition ($\chi^2(3) = 56.23, p < .001$). This main effect of condition was driven by the number of glances made during both the Visual-Manual and Visual-Voice being significantly greater than Baseline. The number of glances made increased by a risk factor of 0.36 during the Visual-Manual condition ($p < .001$) and 0.61 in the Visual-Voice condition ($p < .001$). There was no significant difference between the number of glances made during Baseline and the Audio-Voice condition.

Table 1 shows the number of glances of each duration interval (<1 s, 1-2 s, >2 s) towards the emulated MDT display. Overall, short glances (<1 s) most frequently occurred, followed by 1-2 s duration glances, with long (>2 s) glances being least prevalent. To visualise the effect of condition on each glance duration band the proportion of all glances of a particular duration occurring during each condition is also displayed in Table 1. Of all the short duration glances (<1 s), 48% occurred during the Visual-Voice condition, compared with only 35.2% in the Visual-Manual condition. In contrast, 68.8% of the safety critical glances (>2 s) occurred when using the Visual-Manual interface, compared with only 18.8% when using the Visual-Voice interface.

Table 1 Proportion of glances for each duration interval, when using each interface (VM = Visual-Manual, VV = Visual-Voice, AV = Audio-Voice)

	< 1s glance duration	1 -2s glance duration	>2s glance duration
Total	739	125	32
VM	35.2%	52%	68.8%
VV	48.0%	40.8%	18.8%
AV	9.1%	3.2%	6.3%

Discussion

The interface modality of the MDT in police vehicles has implications for driver distraction. In conjunction with simulated driving, the current study required

participants to attend to a secondary task using an emulated MDT. The traditional MDT interface modality (Visual-Manual) resulted in significantly less time looking at the forward road way, compared to completing the same task using either a Visual-Voice or Audio-Voice interface. Critically for road safety, the greatest proportion of long duration glances (>2 s) occurred while using the Visual-Manual interface. Visual output interfaces require a significantly greater number of glances towards the display than the Audio-Voice interface. When compared to Baseline, results suggest that a Visual-Voice interface requires significantly more glances in total, however this represents a smaller proportion of the long duration glances (>2 s). The long duration glances away from the road are known to elevate crash risk (Dingus and Klauer 2008, Klauer et al. 2006, Horrey 2011). Results from the current study suggest that if an MDT is used while driving police vehicle drivers may be putting themselves and others at risk due to the nature of glance pattern required to operate a manual input device. The impacts of these findings on real-world risks need to be established.

The Visual-Manual condition resulted in significantly longer mean glance duration as well as an increased proportion of longer duration glances (>2 s). Although, longer mean glance duration represents some concern for road safety, it is those glances of longest duration which are likely to pose the greatest risk (Horrey and Wickens 2007). Safety critical glances were considered to be of >2 s, as glances of this duration have been linked to increased risk of crash/near crash (Dingus and Klauer 2008, Klauer et al. 2006) and impaired vehicle control (Ryu et al. 2013). While, longer glances away from the road have great potential to be safety critical it is difficult to quantify the exact duration at which a glance becomes safety critical. Other factors also influence safety, such as, how task information is presented, how easy-to-use an interface is and the demographics of the participant population tested (Green 2008). While there is evidence that longer duration glances are the more critical for road safety (Horrey and Wickens 2007) further research is required to precisely define the safety critical glance.

Despite the similarity of the task between conditions, participants responded to the differing interface modalities by adopting different glance duration behavior. Such adaption of attention allocation is in-line with previous research utilising self-paced secondary tasks (Metz et al. 2011, Jamson et al 2004). In terms of glance patterns, the best interface for mitigating the effects of driver distraction was the Audio-Voice interface. When using the Audio-Voice interface participants were able to maintain their baseline glance pattern. Furthermore, use of voice input modality may alleviate some of the potential driving impairment observed when undertaking a dual task paradigm (Maciej and Vollrath 2009, Ranney et al. 2005). Voice input interfaces would also have positive implications for ergonomic seating issues within police vehicles. Use of a voice input interface would negate the necessity for a driver to twist in their seat to manually interact with the MDT, therefore reducing the inappropriate muscle activation which may lead to musculoskeletal pain (McKinnon et al. 2012). However, the ambient noise experienced during police vehicle travel has the potential to render an audio output difficult to practically implement.

Although no significant differences were reported between the Audio-Voice and Baseline condition it should be acknowledged that any secondary task will require some auxiliary cognitive load and mental processing. It has been demonstrated that this additional load can result in fixation of glances within the central region of the road environment and reduced attention towards the periphery (Victor et al. 2005). A limitation of the current protocol is a lack of information as to real-life exposure of

MDT use while driving. It is possible that an individual's ability to perform a task while driving may be influenced by prior experience. The repeated measures design of the current study ensured an equal influence of such experience during each condition.

There may be additional limitations regarding the functionality of an Audio-Voice system. For instance, the navigation of auditory menus takes more practice than manual interaction (Sodnik et al. 2008), and there may be concerns regarding the accuracy of Voice recognition. The issue of accuracy when recording information using *police* in-vehicle technology has important implications beyond those for *civilian* populations as police work conducted in-vehicle may potentially be used as evidence in court. Within the current study it was desirable for the three conditions to be comparable. As such, the screen used was an emulation of an MDT, containing only information specifically relevant to the task, with simpler layout than a real MDT. Further, to avoid problems of voice recognition accuracy a simulated Audio-Voice system was utilised. It is important that interface modality does not impose limits on police requirements; as such an Audio-Voice interface may not be suitable for all tasks.

It is recognised that there are individual differences in the amount of risk a person is willing to take, in terms of driving time with eyes off road (Fuller et al. 2012). Consequently, some police vehicle drivers may not undertake long duration glances in order to complete a secondary task. However, it is not known how glance behavior would be altered if the driver is under pressure. For example, future work may wish to consider investigating MDT use when under pressure from the driving task (such as engaging in a police chase) in comparison to being under pressure to complete the secondary task as fast as possible.

Since its introduction the MDT has become an important component of police in-vehicle technology and has improved the productivity of police work (Hampton and Langham 2005). While it is recognised that police vehicle drivers are not advised to interact with the MDT while driving, in practice this sometimes occurs, particularly when there is only one police officer (i.e., the driver) in the vehicle (Hampton and Langham 2005). Consequently, the current study focused on single occupancy vehicles. The frequency with which police officers work alone will vary between police forces and may be influenced various factors, such as staffing costs. Future research may wish to consider implications for driver distraction if MDT use is shared between the driver and a partner officer in the vehicle passenger seat.

Enhancement of interface modality has potential to go some way in mitigating the distracting consequences of operating in-vehicle technology. The greatest reduction in driver distraction could be expected by introduction of an Audio-Voice interface. Increasing the functionality of police vehicle cabs through the introduction of voice interaction technology has previously been proposed (Kun et al. 2005). However, it is important to consider practical limitations for Audio-Voice interfaces. Alternately, a Visual-Voice interface offers an environment where the capacity to present information is maintained, whilst distraction to the driver is reduced (compared to Visual-Manual). On the basis of these results, a voice-based MDT is likely to offer the best outcome regarding eyes on the road. These results have implications for developers, purchasers and users of police in-vehicle technology. Using a Visual-Manual interface may expose the user to a greater risk of crash or near crash. Given the necessity of police in-vehicle technology to modern policing and the potential for engagement with such technology while driving, the development and the use of a voice-based interface is recommended.

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Figure 1 Location of the visual display in the simulator vehicle

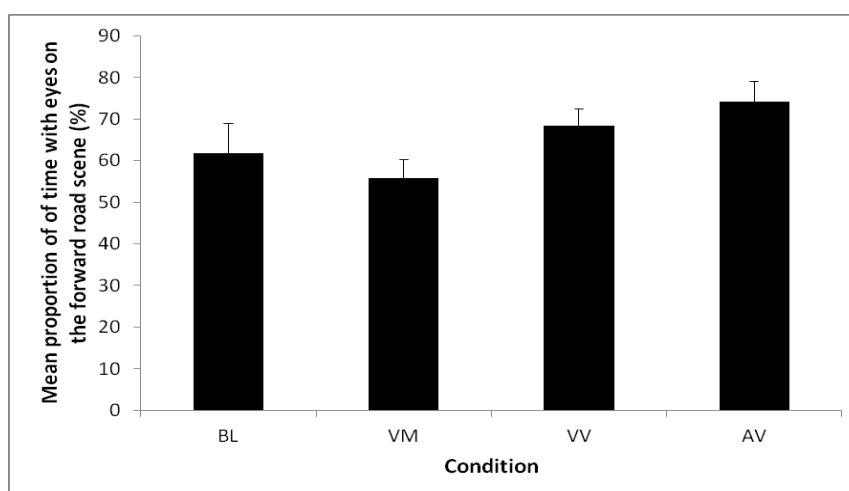


Figure 2 Mean percentage of time with eyes on the forward road scene (error bars represent standard error. BL = Baseline, VM = Visual-Manual, VV = Visual-Voice, AV = Audio-Voice)

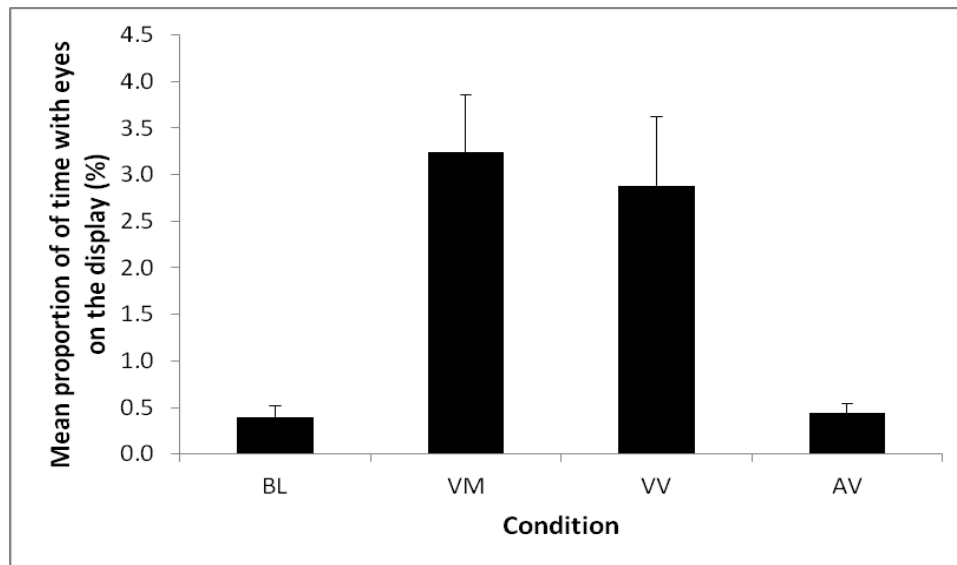


Figure 3 Mean percentage of time with eyes on the display (error bars represent standard error. BL = Baseline, VM = Visual-Manual, VV = Visual-Voice, AV = Audio-Voice)

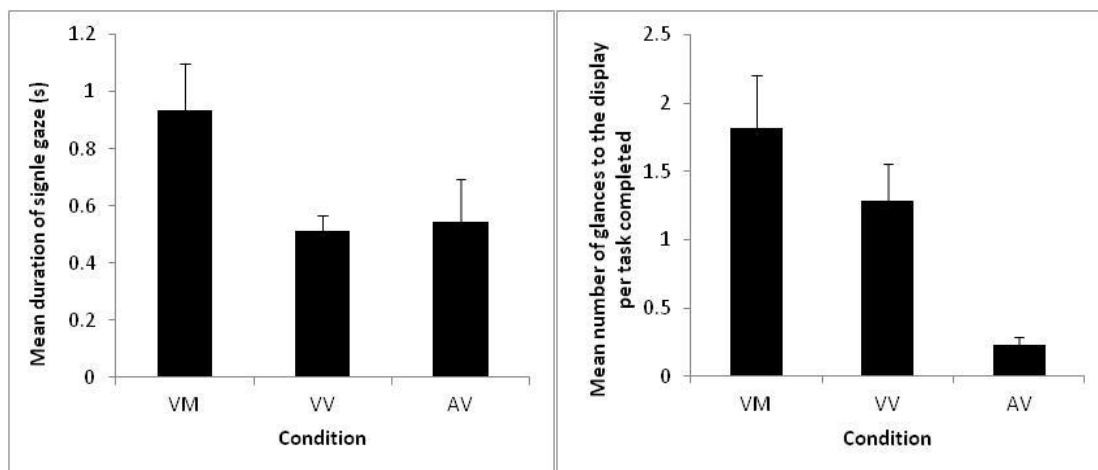


Figure 4 Glance characteristics. Mean glance duration on the display (left) and mean number of glances per task completed (right) (error bars represent standard error. VM = Visual-Manual, VV = Visual-Voice, AV = Audio-Voice)