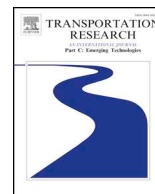




Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Drivers' response to speed warnings provided by a smart phone app

Nicola J. Starkey^{a,*}, Samuel G. Charlton^a, Neha Malhotra^{a,b}, Esko Lehtonen^c^a Transport Research Group, School of Psychology, University of Waikato, Hamilton, New Zealand^b National Youth Sports Institute, Singapore^c VTT Technical Research Centre, Finland

ARTICLE INFO

Keywords:

App
 Distraction
 Driver behaviour
 Speed
 Intelligent speed advisory
 Technology

ABSTRACT

The distractive effects of mobile phones are well documented, but the recent development of mobile phone apps that provide speed advisory warnings raises the possibility that this technology may be used to improve driver safety in older vehicles. We examined the effects of an intelligent speed advisory (ISA) app on driving performance in a simulator. One hundred and four participants (mean age = 35.52 years; 52 male) were allocated to complete the drive with the ISA app in one of five modes: active audio visual (n = 22), active visual (n = 22), passive audio visual (n = 21), passive visual (n = 21) or control (n = 18). Another 19 participants (mean age = 27.53 years; 8 male) completed the study wearing eye-tracking glasses. Participants drove a simulated 26.4 km section of rural road which incorporated typical hazards and three speed compliance zones (100 km/h, 80 km/h and 60 km/h speed limits). The app led to good compliance with the posted speed limits, particularly during the 60 km/h road segment, where the control group drove at significantly higher speeds than the groups with the ISA app. No significant differences between the four versions of the ISA app were observed, either for speed compliance or the number of speeding alerts received. Across the entire simulated drive there were relatively few glances at the app with an average glance duration of 190 ms.

The ISA app did not lead to any negative effects on driving performance; lane keeping was maintained and it did not impede participants' ability to overtake vehicles. These findings suggest that when properly configured ISA apps have a demonstrable safety benefit and do not produce adverse distractive effects. The greatest challenge may be encouraging drivers' to use them appropriately and consistently.

1. Introduction

Manufacturer installed in-vehicle information systems (IVIS) in newer vehicles are designed to provide various types of assistance to the driver, including speed advisory warnings. Similar functionality is becoming increasingly available to drivers of older cars via 'apps' that can be run from a smartphone. These apps provide an important means of improving driver safety, particularly in countries with an older vehicle fleet. In New Zealand for example, the average age of the light vehicle fleet was 14.4 years in 2017, as compared with 10.1 years in Australia and 7.4 years in Europe (MoT, 2019). However, with the well documented negative effects of phone use/distraction on driving, it is crucial to determine if apps delivered via a smartphone result in net improvements in driver safety/behaviour.

* Corresponding author.

E-mail address: nicola.starkey@waikato.ac.nz (N.J. Starkey).<https://doi.org/10.1016/j.trc.2019.11.020>

Received 8 July 2019; Received in revised form 10 October 2019; Accepted 22 November 2019

Available online 29 November 2019

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1.1. Distraction and driver behaviour

A plethora of studies have evaluated the effects of mobile phone use on driving. An early case-crossover study by Redelmeier and Tibshirani (1997) found that drivers using a mobile phone were four times more likely to be involved in a crash; Odds Ratio (OR) = 4.3, [95% CI = 3.0, 6.5], compared with drivers not using a phone. Interestingly the increased crash risk was observed whether or not the phone was hand-held or hands free (McEvoy et al., 2005) indicating the importance of cognitive load in driver safety.

A recent systematic review and meta-analysis found that distraction from hands-free and/or hand-held phone conversations resulted in increased reaction time to a hazard, increased detection reaction time and poorer hazard detection, as well as increased collisions compared to phone-free driving (Caird et al., 2018). Studies examining the effects of secondary visual search tasks (arguably even more analogous to using an IVIS related app than a phone conversation) on driver behaviour report a variety of adverse effects including: reduced following distances, shorter time-to-collision and inappropriate speed (Jamson and Merat, 2005); slower visual scanning (saccades), steering neglect and overcompensation (Liang and Lee, 2010); and poor lane position and increased standard deviation of lane position (SDLP) (Engström et al., 2005; Jamson and Merat, 2005; Liang and Lee, 2010; Tsimhoni et al., 2004).

The above studies highlighted the potential for visual distraction from the use of IVIS related apps to result in negative effects on safety, but these studies assume that drivers interact with or monitor the information from the app frequently. In reality, this is not the case as drivers are able to self-regulate their interaction with distracting in-vehicle devices. Simulator studies have shown that drivers do not engage in secondary tasks in situations they expect to be demanding (Metz et al., 2011; Schömig et al., 2011) whilst findings from on-road studies, suggest that drivers adjust (i.e. decrease) their glance length to in-vehicle devices in more demanding traffic situations (Kircher et al., 2014; Tivesten and Dozza, 2014). It is worth noting, however, that visual displays and auditory alerts can draw attention and increase load simply by virtue of their presence (Kircher et al., 2014). In sum, the potential benefits of IVIS related apps, such as speed-related advisory information, need to be weighed against the potential for visual distraction and possible adverse safety outcomes.

1.2. Speed choice and speed limit compliance

Excessive speed is an important contributing factor to the severity of injuries and the risk of crashes (Aarts and Van Schagen, 2006; Elvik, 2013), and encouraging compliance with posted speed limits is an ongoing challenge in the transport sector. The reasons why drivers exceed the speed limit vary. There is evidence that in some cases speeding is intentional, (Haglund and Åberg, 2002), but speed choice is also governed by other factors including habit, (De Pelsmacker and Janssens, 2007), risk perception (Wilde, 1986), task difficulty (Fuller, 2005), the look and feel of the road (Charlton et al., 2010) and the actual speed limit, indicated by signs. However drivers often fail to notice road signs (Charlton and Starkey, 2013; Harms and Brookhuis, 2016) and when they do, their speed tends to increase as they travel further from the sign (Jongen et al., 2011). Given these issues, the continuous provision of speed limit information via IVIS or an intelligent speed assistance app (ISA) has the potential to offer significant safety benefits by reducing speeding behaviour (Varhelyi, 2002; Carsten, 2012).

A number of studies have examined the effects of different types of ISA systems on drivers' speeds. Unsurprisingly, ISA systems that actively prevent the driver from speeding (rather than simply warning drivers) lead to a reduction in speed and an increase in speed homogeneity (i.e., more consistent speeds), but these effects were only apparent when the ISA was active. Both the mean speed and speed distribution returned to baseline levels when the devices were turned off (Lai and Carsten, 2012), suggesting that 'forced' speed limit compliance did not lead to persistent changes in driver behaviour.

Tests of a voluntary ISA system (simulator and instrumented car) found a decreased propensity to speed, but the effect was mostly confined to lower speed limits (Jamson, 2006). Drivers engaged the ISA for approximately half of the time, and used it more on high speed limit roads. In low speed limit zones drivers intentionally deactivated the ISA in order to speed. In the on-road trials, when driving on a low speed rural road drivers reported a need to keep up with traffic, and disengaged the ISA. In addition, drivers who reported enjoying speeding were less likely to use the ISA, a finding replicated in a long-term field-study by Lai et al. (2010), indicating that drivers who most needed it were least likely to use it.

A longitudinal study examining the effectiveness of speed 'advisory' systems, found that the speed reducing effects were greatest when the system was first introduced. The time spent speeding decreased by 75% at the beginning of the trial, but towards the end of the study speeding had risen to 50% of baseline, suggesting the drivers had partially habituated to the speed advisory system, or the drivers simply failed to comply. However, even after three years the drivers sped less than before the activation of the system, indicating that the ISA was effective in reducing speeding (Warner and Åberg, 2008). Interestingly though, speeds returned to baseline levels if the system was removed, suggesting that ISAs need to be constantly active to improve speed limit compliance (Chorlton and Connor, 2012).

ISAs also appear to be effective when used to target specific high risk driving situations. For example, Whitmire et al. (2011) examined the effectiveness of an ISA application designed to reduce speeding at roadworks sites. Both visual and visual-auditory speed advisories were found to reduce the time participants spent speeding relative to a control condition during a simulated drive. Together these studies indicate that ISAs provide significant benefits in terms of speed limit compliance, but in some situations their use has had unanticipated negative effects. An on-road study of a driver assistance system designed to warn drivers about departures from desirable speeds and lane position, found that, as hoped, drivers selected lower speeds on curves, but when turning at intersections their speed was too high, possibly because they received no speed related alert from the system (Várhelyi et al., 2015). In

addition, Jamson et al., (2012) suggested that ISAs may reduce overtaking, or cause drivers to take unnecessary risks when overtaking, because drivers would not have enough space to complete the manoeuvre at the lower speeds programmed into the advisory system.

This brief overview of the literature highlights an inherent tension or trade-off between the potential benefits an app-based ISA might confer to drivers of older vehicles, and their potential to decrease safety by distracting drivers. In addition, there is the potential for ISAs to lead to unanticipated changes in driver behaviour in specific situations, such as negotiation with other traffic. Thus, it is unclear whether the use of an app-based ISA will have in a net safety benefit. To address this, we investigated the potential adverse effects of an ISA mobile phone app and examined its effects on the driving performance of participants in the University of Waikato driving simulator. The app was designed so that we could investigate whether ISAs that placed varying manual (active/passive) and cognitive demands (audio/visual) influenced driver behaviour in different ways. The overall design of the app and the testing procedure were informed by best practice guidelines for in-vehicle systems (Kroon et al., 2016; NHTSA, 2012). Specifically the guidelines were used to inform the design of the ISA display, the position of the smartphone in the car, and to inform the driver performance parameters tested in the current study, for example it is recommended that 85% of the glances off the road should be less than two seconds and the total eyes off the road time per task should not exceed 12 s.

The aims of the study were:

1. To measure how driving performance (i.e., speed choice, compliance with the information presented and overtaking behaviour) changed in response to the information provided by an ISA mobile phone app presented in different presentation modes.
2. To assess how drivers' reactions to road and traffic situations were affected by the potential distraction produced by different display modes associated with an ISA mobile phone applications (assessed via SDLP and glance duration to the ISA).

2. Method

2.1. Participants

One hundred and forty four participants with a full New Zealand driver licence were recruited for the study via community noticeboards and electronically via university communication channels. Of these, 123 individuals completed the study (62 males, 61 females) with a mean age of 34.46 years ($SD = 13.04$, range 18–64 years) (data from the other participants was discarded due to equipment failure or simulator sickness). In terms of ethnicity, 76 participants identified as New Zealand European, 18 as Māori, and 45 as other (participants were able to select all that applied, hence the total exceeded 123). When asked about their use of technology whilst driving, 107 participants (87%) reported using a mobile phone when driving. They were most frequently used for navigation ($n = 82$, 66.7%) followed by phone calls ($n = 57$, 46.3%), music ($n = 56$, 45.5%) texts ($n = 32$, 23%) and social media ($n = 4$, 3.3%). Fifty four (43.9%) participants had access to a manufacturer installed in vehicle information system that was used for entertainment ($n = 30$, 24.4%), monitoring fuel efficiency ($n = 18$, 14.6%), navigation ($n = 15$, 12.2%), parking assistance ($n = 14$, 11.4%), lane departure warnings and collision avoidance ($n = 4$, 3.3% for each). None of the participants reported using an ISA system previously. In terms of their crash history, 15 participants reported being involved in a crash in the past year when they were the driver, of these 11 reported being involved in 1 crash, 3 reported being in 2 crashes and 1 person reported being in 3.

One hundred and four participants were assigned to a simulator only group and the remaining 19 were assigned to a group whose eye movements were tracked while they completed the simulated driving task (participants in this group had to be able to drive without glasses or corrective lenses). The eye tracking group were significantly younger [$F(1,111) = 5.01$, $p = .03$ and therefore had less licensed driving experience [$F(1,121) = 7.52$, $p = .007$] compared with those in the simulator only group. There were no significant differences between the groups in relation to average weekly distance driven ($p = .60$) or the proportion of males and females in each group ($X^2 = 0.05$, $p > .05$).

Participants in the simulator only group were pseudo randomly allocated (balanced for gender) to one of five conditions related to the display mode of the ISA; active audio visual ($n = 22$), active visual ($n = 22$), passive audio visual ($n = 21$), passive visual ($n = 21$) or control ($n = 18$). Those in the eye tracking group were allocated to one of three ISA conditions; active audio visual, passive audio visual or control (see Section 2.2.3 for more details about the ISA). The demographic details of participants in each of the experimental conditions for the simulator only and eye tracking groups are summarised in Tables 1 and 2. There were no statistically significant demographic differences across the conditions for participants in either group.

Ethical approval for the recruitment and test protocols was received from the School of Psychology Research and Ethics

Table 1

Demographic characteristics of the participants in the simulator only group.

| | Active audio visual ($n = 22$) | Active visual ($n = 22$) | Passive audio visual ($n = 21$) | Passive visual ($n = 21$) | Control ($n = 18$) | Test of difference |
|----------------------------------|-------------------------------------|-------------------------------|--------------------------------------|--------------------------------|-------------------------|-------------------------------|
| Age in years (mean, SD) | 34.09 (11.98) | 35.00 (15.11) | 32.38 (12.98) | 42.67 (14.64) | 32.08 (8.08) | $F(4, 93) = 2.11$, <i>ns</i> |
| Male (n , %) | 11 (50) | 11 (50) | 10 (47.6) | 11 (52.4) | 9 (50) | $X^2 = 0.09$, <i>ns</i> |
| Years licensed driver | 14.91 (12.14) | 16.73 (15.14) | 14.90 (12.67) | 25.57 (13.91) | 18.06 (11.47) | $F(4, 99) = 2.37$, <i>ns</i> |
| Km driven per week (mean, SD) | 426.60 (1472.34) | 368.64 (559.89) | 135.48 (98.44) | 194.29 (215.70) | 176.76 (161.22) | $F(4, 98) = 0.64$, <i>ns</i> |

Table 2

Demographic characteristics of the participants in the eye tracking group.

| | Active audio visual (n = 6) | Passive audio visual (n = 6) | Control (n = 7) | Test of difference |
|-------------------------------|-----------------------------|------------------------------|-----------------|-------------------------------|
| Age in years (mean, SD) | 30.33 (7.10) | 26.00 (5.70) | 25.25 (5.74) | $F(2, 12) = 1.00$, <i>ns</i> |
| Male (n, %) | 3 (50) | 3 (50) | 2 (28.6) | $\chi^2 = 3.72^a$, <i>ns</i> |
| Years licensed driver | 9.17 (6.24) | 6.00 (5.73) | 12.14 (7.52) | $F(2, 16) = 1.40$, <i>ns</i> |
| Km driven per week (mean, SD) | 150.00 (174.24) | 143.83 (181.30) | 225.70 (171.65) | $F(2, 16) = 0.45$, <i>ns</i> |

^a Fisher's exact test – cell counts less than 5. *ns* = not statistically significant, $p > .05$.

Committee at the University of Waikato (#17:41). Each of the participants received a \$20 gift voucher to thank them for taking part.

2.2. Apparatus and materials

2.2.1. Driving simulator

Participants completed the driving task in the Transport Research Group driving simulator consisting of a complete automobile (2010 Toyota Prius plug-in) positioned in front of three angled projection surfaces (Fig. 1). The centre projection surface was located 2.32 m in front of the driver's eye position with two peripheral surfaces connected to the central surface at 52° angles. The projection surface was angled back away from the driver at 4.3° (from the bottom to the top of the projection surface) and produced a 178.2° (horizontal) by 33.7° (vertical) forward view of the simulated roadway from the driver's position. The image projected on the central surface was 2.6 m wide by 1.47 m high (resolution of 1920 by 1200 pixels) and each of the two peripheral images were 2.88 m by 2.15 m (resolution of 1024 by 768 pixels). Two colour LCDs were mounted at the centre rear-view mirror and driver's wing mirror positions to provide views looking behind the driver's vehicle. The simulated vehicle's performance was determined by a multi-body vehicle dynamics model configured as an automobile with automatic transmission and power steering. The images and vehicle model were updated at a minimum rate of 100 frames per second. The simulation software recorded the participant's speed, lane position and control actions automatically throughout the simulation scenario. The simulator hardware and software was developed by the Transport Research Group and has been tested and validated against on-road performance across a wide range of experimental scenarios (e.g., Charlton and Starkey, 2013, 2016; Charlton, Starkey and Malhotra, 2018).

2.2.2. Eye tracking

Tobii Pro Glasses 2 were used to monitor the eye movements of the 19 participants in the eye tracking group whilst they completed the drive. The Tobii Pro Glasses are a wearable eye tracker (with a sample rate of 100 Hz), fitted with a high-definition scene camera (82° horizontal, 52° vertical field of view with 1920 × 1080 resolution at 25 frames per second), a microphone, binocular eye tracking sensors (field of view > 160° horizontally, 70° vertically), infra-red illuminators and accelerometer and gyroscope sensors. The glasses were connected via a HDMI cable to a pocket size recording unit which contained the batteries and stored the recorded data on a secure digital (SD) card. The eye tracker was controlled wirelessly and secured with a strap (around the back of the head) to minimise slippage prior to calibration.

Gaze data were analysed with Tobii Pro Lab 1.58. Fixations were detected using IV-T algorithm with preset parameters from the Tobii Pro Lab I-VT (Attention). The fixation detection used a liberal 100° velocity threshold so head movements and pursuit movements were not misclassified as saccades, and a single fixation typically corresponded to a single glance to the speedometer or the app. Velocity was calculated with a 20 msec window. The raw data was first run through a moving median filter with a three-sample window to reduce noise. Fixations were required to be at least 60 msec long and adjacent fixations within 75 msec and 0.5° of visual angle were merged. The frequency and duration of the fixations to the ISA and the in-vehicle speedometer were calculated.

2.2.3. Intelligent speed assistance system

The intelligent speed assistance (ISA) software was displayed on a Microsoft Lumia 640 XL Smartphone (display size of 2.7 in.,



Fig. 1. The Applied Cognitive/Transport Research Group driving simulator.



Fig. 2. The location (left panel) of the smartphone in the car and the ISA display (right panel).

resolution of 1280×720 and pixel density of 259 pixels per inch). The smartphone was mounted on the centre console 12 cm to the left of the steering wheel. Visually, the display was located 10.6° below, and 29.3° to the left of the driver's forward line of sight (Fig. 2).

The software, developed specifically for this project in accordance with best practice guidelines (Kroon et al., 2016; NHTSA, 2012), was designed to alert the driver when they exceeded the posted speed limit. Start-up of the ISA was signalled by a short welcome tone when the driver reached the end of the baseline section of the road. After this the display showed a large rondel in the centre of the screen, with the current speed limit. Smaller rondels displaying available speed warning choices (30, 50, 60, 70, 80 and 100) were shown at the bottom of the screen and matched the NZ speed limit signs used in the simulation scenarios (Fig. 2). The ISA was designed to provide two types of alert (visual only or auditory and visual (i.e., AV)) and operate in two modes (active or passive). The active mode required the driver to select the correct speed by touching the display, which we compared to a fully automatic (passive) mode, a best case automation scenario (even though it is not currently available in NZ) so that we could assess the potential distractive effects associated with manipulation of the IVIS. This resulted in four experimental conditions; active AV; active visual, passive AV and passive visual, plus a control group where the ISA remained off with a blank screen throughout the drive.

Speeding (defined as exceeding the speed limit by 4 km/h or more for at least three seconds) was accompanied by the main speed rondel flashing on/off (each state 0.5 s) until the participant reduced their speed to within 4 km/h of the speed limit. For the audio visual conditions the flashing rondel was accompanied by a beep, synchronised with the flashing, until speeding stopped. Our operational definition of speeding for this study was based on the minimum enforcement tolerance commonly used by the NZ Police and thus familiar to our participants.

In the passive modes (AV and visual), the ISA display automatically updated to show the new speed limit seven seconds after entering a new speed zone. In the active modes, the participants were told to select the new speed limit from the selection of small rondels at the bottom of the screen when they entered a new speed zone (as indicated by speed limit signs at the left and right edge of the road). Successful selection of the new speed was confirmed by a beep and the new speed was displayed in the large rondel. If the driver entered a new speed zone and failed to select a new speed, the ISA updated automatically seven seconds after entering the new speed zone (as in the passive mode). Therefore, to provide the greatest possible comparison, the only difference between the active and passive groups was the instructions given to the participants. In all conditions, the ISA automatically switched off, indicated by a short 'shutting down' tone, for the final section of the drive (2.8 km from the end).

2.2.4. Simulation scenario

The simulation scenarios used for this study were based on a 26.4 km-long section of rural road containing a combination of straights and gentle horizontal and vertical curves (Fig. 3). The road geometry was an accurate representation of a rural two-lane state highway in New Zealand and was based on the surveyed three-dimensional road geometry. Lane widths were based on road survey data from the road controlling authority, and road markings were consistent with Transport Agency guidelines. The road contained 26 intersections, and at seven of the intersections stationary cars were positioned to enter the road. It took approximately 20 min to complete the drive at the posted speed limits. Oncoming traffic (76 cars and trucks) was included to represent a traffic density of approximately 1500–2000 vehicles per day.

The road was divided into nine approximately equal sections with different posted speed limits (60 km/h, 80 km/h and 100 km/h). The first and last sections were designated as baseline conditions and were driven with the IVIS turned off. The mid-section of the drive contained three 'speed compliance zones' depicting standard New Zealand rural roads, with minimal hazards and posted speed limits of 100 km/h, 80 km/h and 60 km/h.

In the four remaining sections the participants experienced common driving hazards: reduced speed at roadworks, a busy intersection, a single lane bridge and an overtaking lane (Fig. 4). The speed compliance zones (described above) and drivers' behaviour through the overtaking zone were the focus of the current study. In the overtaking scenario, drivers encountered a slow truck (78 km/

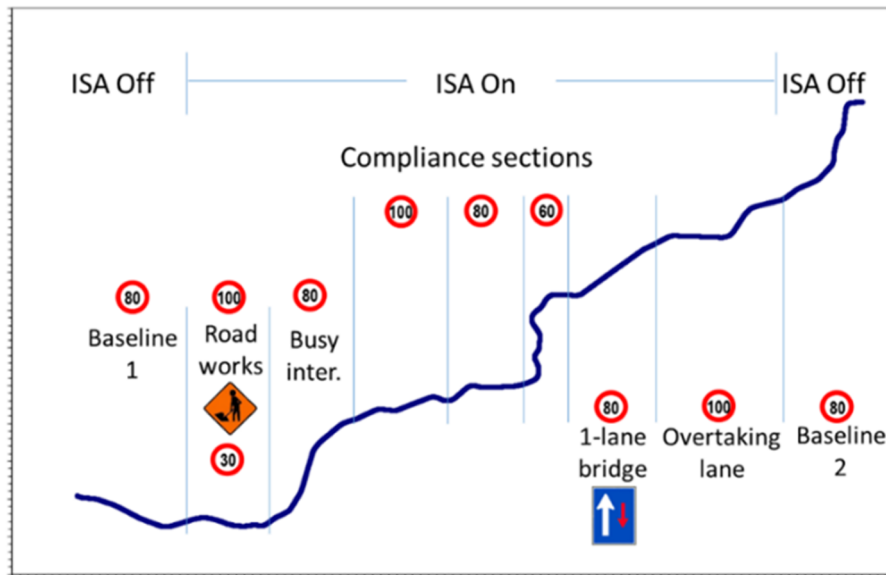


Fig. 3. A map of the 26.4 km simulated road used for the simulated drive.

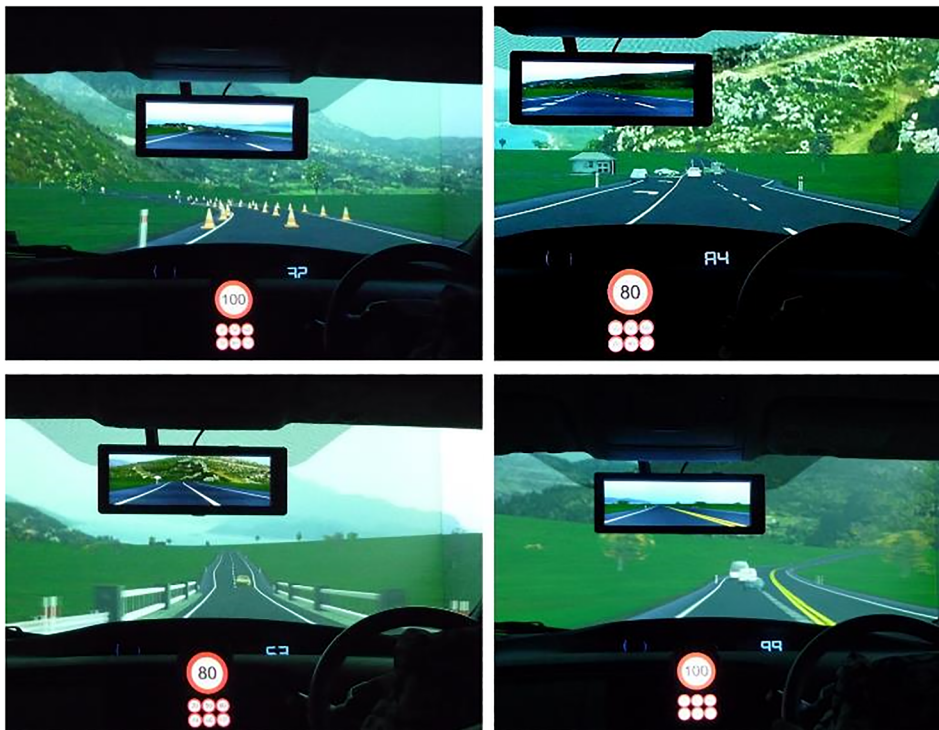


Fig. 4. Scenes from the simulation scenario: the roadworks (top left), busy intersection (top right), one lane bridge (bottom left) and overtaking lane (bottom right).

h) being followed by a van and then a car, all travelling uphill. A sign on the left advised there was an overtaking lane 400 m ahead. At the start of the overtaking lane (1 km in length) the truck remained in the left-hand lane and the car and van overtook the truck at 84 km/h. After passing the truck, the van then moved to the left ahead of the truck and the leading car accelerated to 120 km/h. Depending on the participants' following distance, they could overtake the truck and the van (but not the car) without exceeding the speed limit.

2.2.5. Post- drive questionnaire

After the drive, participants were asked to complete an online questionnaire. The first section asked them to rate the ISA system using a 5-point semantic differential scale (–2 to +2) with nine items (useful – useless, pleasant – unpleasant, bad – good, nice – annoying, effective – superfluous, irritating – likeable, assisting – worthless, undesirable – desirable, raising alertness – sleep-inducing) with items 3, 6 and 8 reverse scored (Van der Laan et al., 1997). Answers were re-coded so a higher score reflected a more positive evaluation. Two scores were calculated: a usefulness score based on the average of items 1, 3, 5, 7 and 9, and a satisfying score based on the average of items 2, 4, 6 and 8 (scores could range from –2 to +2). The final section asked for demographic and driving history information.

2.3. Procedure

When participants arrived at the laboratory the purpose of the study was explained to them, any questions they had about the study were answered and they provided written informed consent. Participants were then seated in the car and were given standardised instructions on how to operate the driving simulator; to use the accelerator to speed up, the brake to slow down, and to gently steer to match the speed they would usually drive on these types of roads in their own car. Participants were also told that on the practice road the speed limit would be 80 km/h or 100 km/h and that the car was equipped with a speed advisory system that would remind them if they were speeding. Participants in the AV conditions were told that speeding would be indicated by a warning sound being played from the smart phone as well as the flashing display; those in the two visual-only groups were told that speeding would be indicated by the display flashing on the smart phone in the centre console. Participants completed a 3 km practice drive first without and then with the ISA. Those in the active conditions were asked to update the warning speed on the ISA when they reached a new speed limit, whereas participants in the passive conditions were told that the speed limit on the ISA would automatically change a few seconds after they entered a new speed zone.

After the second practice drive, participants were instructed to drive the simulated road just as they would in their own car, obeying the road rules and if they wanted to overtake a slow vehicle they could, if they would usually do so in their own car. The participants were also reminded to use the speed advisory (once it turned on) as they had in the practice drive.

At the end of the drive, participants completed the post-drive questionnaire online (hosted on Qualtrics website), they were thanked, given a \$20 gift voucher, and asked if they had any questions or comments. (Note: The procedure for the participants in the eye tracking group was identical other than the eye-tracker calibration prior to commencement of the practice drive).

2.4. Statistical analysis

To address the first research question, how driving performance changed in response to the information provided by the ISA, speed compliance was examined in a number of ways. Initially we calculated participant's average speeds over 110 m sections of road (without intersections or major horizontal or vertical curves) for the first baseline section and the three 'speed compliance zones' (Fig. 3). These data were also used to calculate speed variability and the percent of speeding in each road section. For each measure we used one way Anova to compare the 5 ISA groups in the baseline zone. After this, mixed design 3 (speed compliance zone) \times 5 (ISA group) Anova were conducted (partial eta square was used as an estimate of effect size). This was followed by one-way between group Anova for each of the speed compliance zones and Bonferroni-corrected post-hoc tests as required.

To obtain further information about the effectiveness of the different ISA modes, we compared the length of time that participants in the four ISA conditions spent driving under a speeding alert, as well as the number of alerts they received using one-way Anova. Finally, to determine if the ISA altered participants overtaking behaviour, we calculated the number of vehicles overtaken by each participant in the overtaking lane scenario. Comparison across the five groups were made using Chi square.

The potential distractive effects of the ISA were assessed in two ways. First, the participants' lane position variability was calculated as the standard deviation of their distance from the centre of their lane over the same 110 m road sections described earlier for speed compliance. SDLP is widely considered to be an important indicator of task focus, fatigue and impairment due to distraction, alcohol and drugs (Engström et al., 2005). As in the first set of analyses, a one way Anova was used to compare the baseline SDLP across the 5 ISA groups, followed by a mixed design 3 (speed compliance zone) \times 5 (ISA group) Anova. The second-distraction related analysis focused on the frequency and duration of glances to the ISA and speedometer for 17 participants completing the drive wearing the Tobii glasses (the eye movement data of two participants was not usable). One-way Anova was used to compare frequency and duration of glances across the three ISA conditions (active AV, passive AV and control).

The last section of the results reports the participants' ratings of the ISA device they used. Ratings were compared using a 2 (mode: active or passive) \times 2 (alert: AV or visual only) between groups Anova.

3. Results

3.1. The effect of the ISA on driving performance

There were no significant differences between the ISA groups in speeds driven through first baseline section (without the ISA) [$F(4,99) = 0.765, p = .551, \eta^2 = 0.030$]. The mean speeds for each ISA group in the three compliance zones are shown in Fig. 5. The figure clearly shows that the speeds driven in each zone were close to the posted speed limits. Speeds in the 60 km/h and 80 km/h zones were generally just over the posted limit, and just under in the 100 km/h zone. The mean speeds for each ISA group are similar,

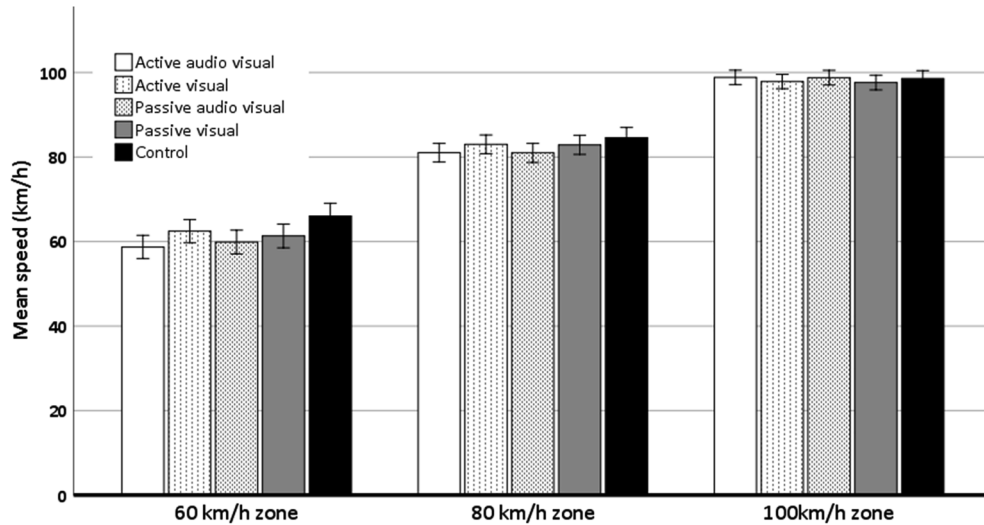


Fig. 5. Mean speeds by ISA group in the three compliance zones. Vertical lines indicate 95% confidence intervals.

apart from the control group driving faster in the 60 km/h zone. These observations were confirmed by the Anova; participants' mean speeds showed significant differences across the three speed compliance zones [$F(2,198) = 1671.355, p < .001, \eta^2 = 0.944$], there was an overall significant difference between the five ISA groups [$F(4,99) = 2.524, p = .046, \eta^2 = 0.093$], and a significant interaction between compliance zone and group [$F(8,198) = 2.266, p = .024, \eta^2 = 0.084$].

To investigate the significant interaction, oneway Anova were conducted for each of the three compliance zones. In the 60 km/h compliance zone there were significant differences in speeds across the five ISA groups [$F(4,99) = 3.65, p = .008, \eta^2 = 0.128$]. Bonferroni-adjusted post hoc comparisons showed that participants in the control group drove significantly faster than participants in the active AV group ($p = .002$) and passive AV group ($p = .014$), but were not reliably different than the passive visual ($p = .083$) or active visual groups ($p = .241$). None of the other ISA conditions differed reliably from one another in the mean speeds observed in the 60 km/h zone. Similar analyses for the 80 km/h and 100 km/h compliance zones failed to reveal any significant differences in speed between the five ISA groups [80 km/h zone $F(4,99) = 1.67, p = .162, \eta^2 = 0.063$; 100 km/h zone $F(4,99) = 0.40, p = .811, \eta^2 = 0.016$].

Across these three road sections there was also a reliable difference in speeds between men and women participants [$F(1,94) = 11.115, p = .001, \eta^2 = 0.106$], as men drove an average of 2.42 km/h faster than the women. There were not, however, any statistically significant interactions between gender and ISA group [$F(4,94) = 0.46, p = .769, \eta^2 = 0.019$], nor gender and compliance zone [$F(2,188) = 2.30, p = .103, \eta^2 = 0.024$]. Adding participant age to the model as a covariate did not change the outcome and did not account for a significant proportion of the variance [$F(1,92) = 1.40, p = .240, \eta^2 = 0.015$].

We also conducted analyses to determine if the variability of participants' speeds differed across the groups (i.e., were speeds compressed because they drove closer to the speed limit?). There were no reliable differences in speed variability across the 5 ISA groups in the first baseline zone [$F(4,99) = 0.96, p = .434, \eta^2 = 0.037$]. Speed variability data for each ISA group in the compliance zones are presented in Fig. 6. There was no significant difference between the five experimental groups (four ISA conditions and control) in their speed variability during the 110 m sections drawn from each speed zone as indicated by a mixed-design Anova [$F(4,99) = 0.96, p = .037, \eta^2 = 0.037$]. The analysis also failed to indicate any interaction between compliance zone and group [$F(8,198) = 0.96, p = .526, \eta^2 = 0.021$], but did show that the speed variability differed significantly across the road sections [$F(2,198) = 21.28, p < .001, \eta^2 = 0.177$]. Speed variability was significantly lower in the 100 km/h zone ($M = 0.75$) compared to either the 80 km/h ($M = 1.45, p < .001$) or 60 km/h zone ($M = 1.17, p < .001$). The difference between the 80 km/h and 60 km/h zones did not reach statistical significance. [Note: The data for these analyses is based on distance travelled and participants would travel through the 110 m speed compliance zone more quickly when travelling at higher speeds, limiting their opportunity to vary their speed].

The next set of analyses focused on the effect of the ISA on compliance with the posted speed limits. Initially, we calculated the percent of the 110 m road sections where the participants in each of the five groups exceeded the speed limit during the first baseline and each compliance zones. There was no significant difference between the mean percent speeding in the baseline (no ISA) section across the 5 ISA groups [$F(4,99) = 0.64, p = .638, \eta^2 = 0.025$]. The mixed Anova did not detect any differences between the five groups [$F(4,99) = 0.79, p = .535, \eta^2 = 0.031$] or significant interaction between zone and group [$F(8,198) = 1.84, p = .071, \eta^2 = 0.069$]. There was however, a significant difference between the three compliance zones [$F(2,198) = 28.07, p < .001, \eta^2 = 0.221$]. Bonferroni-adjusted comparisons indicated that participants exceeded the speed limit significantly more during the 80 km/h section (72.73% of the 110 m section) as compared to the 60 km/h (52.83%) and 100 km/h zones (34.24%; all $ps < .001$).

We then focused on the groups driving with the ISA and calculated the amount of time the participants spent driving with the device alerting them to excessive speed across the seven road sections when the ISA was on (Fig. 7). There were no significant

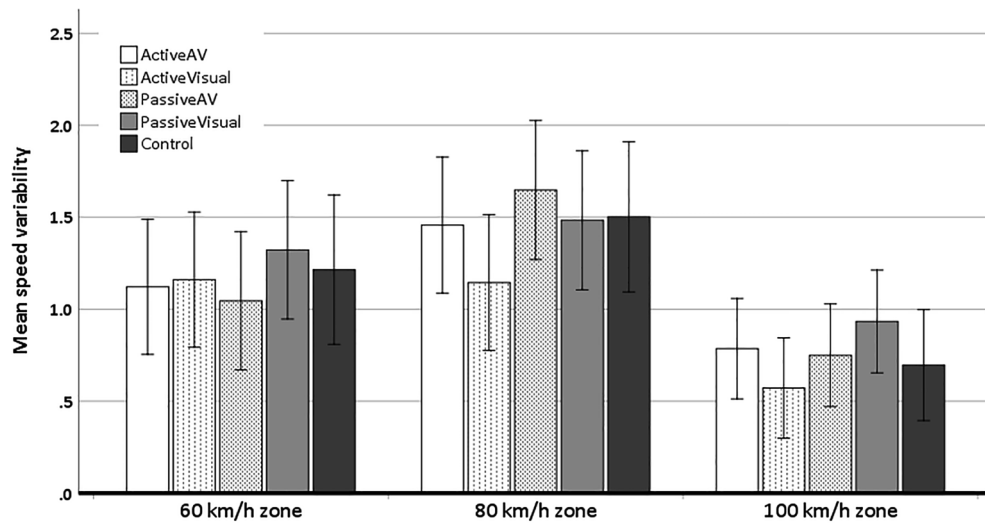


Fig. 6. Mean speed variability for the 5 ISA groups in the three compliance zones. Vertical lines indicate 95% confidence intervals.

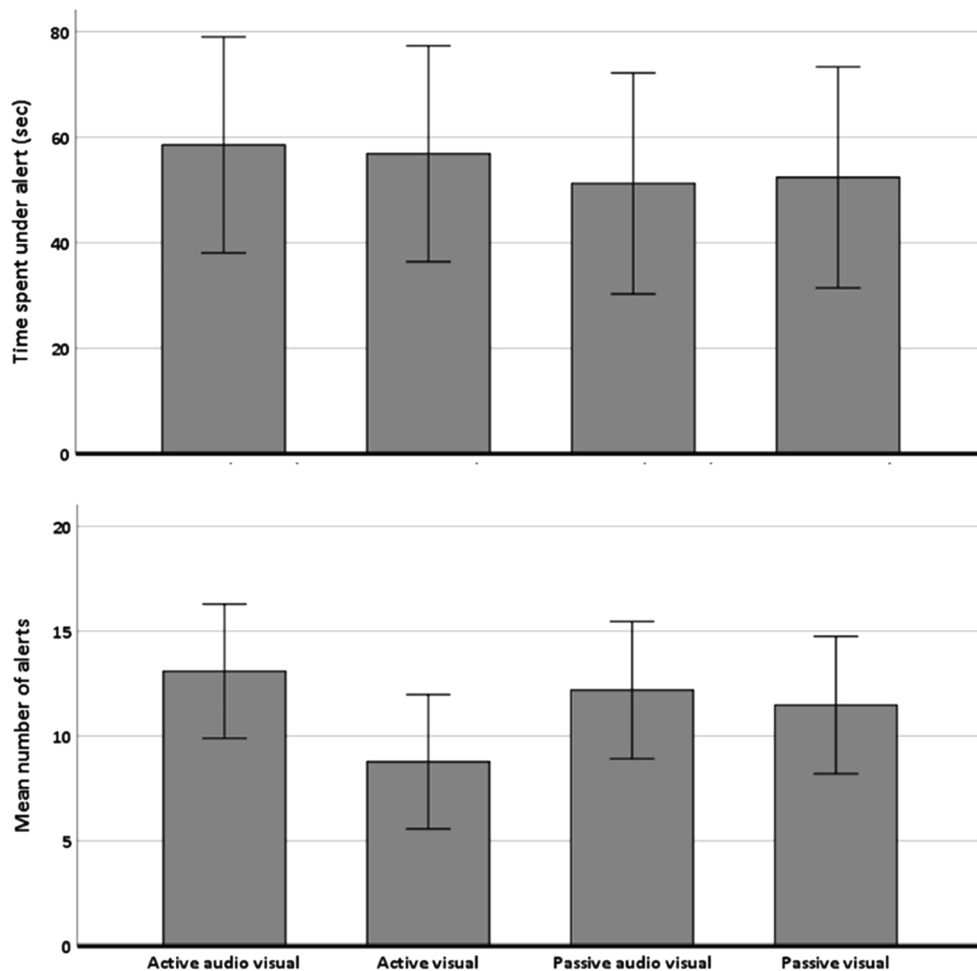


Fig. 7. Participants' average time spent under ISA alert (top) and average number of alerts received (bottom) across the seven road sections. Vertical lines indicate 95% confidence intervals.

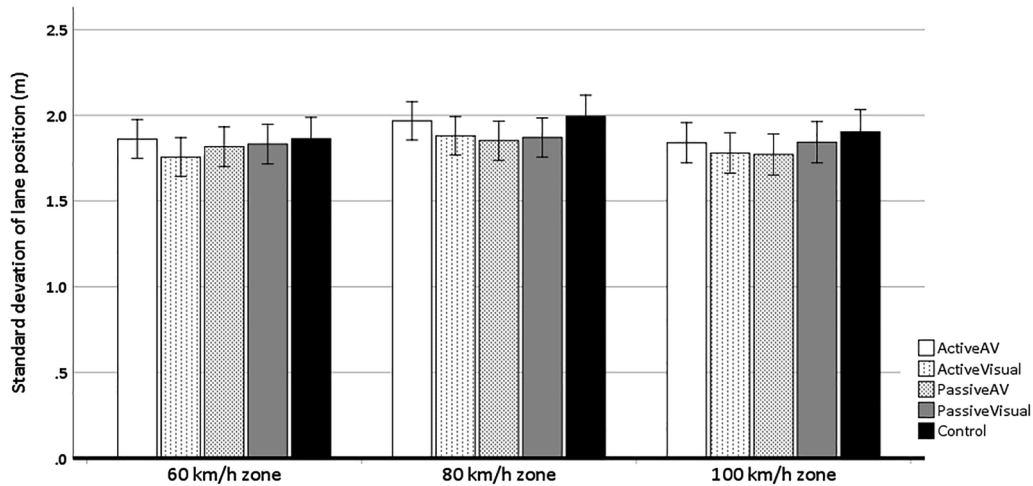


Fig. 8. Lane position variability (SDLP) for each ISA group across the three compliance zones. Vertical lines represent 95% confidence intervals.

differences between the four ISA groups [$F(3, 82) = 0.11, p = .952, \eta^2 = 0.004$]. Similarly, there were no reliable differences between the groups in the number of alerts they received from the ISA [$F(3, 82) = 1.33, p = .269, \eta^2 = 0.047$], as shown in the lower panel of Fig. 7.

Finally, although the participants showed generally good compliance with regard to the ISA system, we were also interested in exploring if the ISA impeded their overtaking behaviour during the eighth section of the drive (overtaking scenario). For each of the five groups the modal number of vehicles overtaken was one. A chi square analysis did not reveal any differences in the numbers of vehicles overtaken across the groups [$\chi^2(12) = 11.01, p = .529$].

3.2. The distractive effect of the ISA

The first analyses focused on standard deviation of lane position (SDLP). There were no statistically significant differences in SDLP between the five groups in the first baseline (no ISA) section [$F(4, 99) = 0.48, p = .7545, \eta^2 = 0.019$]. As shown in Fig. 8, there was no evidence of a significant compliance zone by group interaction [$F(8, 198) = 0.46, p = .881, \eta^2 = 0.018$] or for significant differences between the 5 groups [$F(4, 99) = 0.99, p = .752, \eta^2 = 0.019$]. There was however, a significant difference in the participants' SDLP across the three compliance zones [$F(2, 198) = 7.31, p = .001, \eta^2 = 0.069$]. SDLP was significantly greater in the 80 km/h zone as compared to the 60 km/h and 100 km/h zones ($ps < 0.05$). SDLP in the 60 km/h and 100 km/h zones were not reliably different.

We then examined the visual load associated with the ISA device by calculating glance frequency and total gaze duration for the ISA and, for comparison, the speedometer. As shown in the left panel of Fig. 9, the active group looked at the ISA more frequently and longer than the other two groups. A one-way Anova indicated the difference in the groups' mean glance frequency was significant [$F(2, 14) = 4.65, p = .028, \eta^2 = 0.399$], and the same for total glance duration [$F(2, 14) = 4.04, p = .041, \eta^2 = 0.366$]. Post hoc comparisons (Bonferroni adjusted) indicated that the active group glanced at the ISA more frequently ($p = .026$) and for longer ($p = .040$) than the control group but not reliably more ($p = .265$) or longer ($p = .318$) than the passive group. In contrast, there were no statistically significant differences between the groups' mean glance frequency [$F(2, 14) = 1.87, p = .191, \eta^2 = 0.211$] or total glance duration towards the speedometer [$F(2, 14) = 2.58, p = .111, \eta^2 = 0.269$] (right panel Fig. 9).

The mean duration of individual glances at the ISA device was 155.64 msec (SD = 86.31), significantly shorter than the 281.95 msec (SD = 48.24) mean duration of participants' glances at the speedometer [$F(1, 14) = 23.77, p < .001, \eta^2 = 0.629$]. This was in part due to the control group, whose glances towards their inactive ISA device averaged 122.68 msec (SD = 101.53). On the whole, drivers glanced at the ISA rather infrequently and briefly, and for a total of 0.20% of the drive, much less than they looked at their speedometer, a total of 8.87% of the drive.

3.3. Post-drive questionnaire

After the drive, participants who used the ISA device (i.e., not the control group participants) were asked to provide ratings of the ISA they used (Table 3). In general, participants rated the ISA positively (scores could range from -2 to $+2$) on each of the items, with the highest (most positive) ratings for the likeable–irritating and useful–useless dimensions. In terms of summary scores, the usefulness ratings were higher than the satisfaction ratings. To examine participants' views on the different modes and alerts, provided by the app, further analyses with 2 (mode: active or passive) \times 2 (alert: audio visual or visual only) between groups ANOVAs were conducted. Participants in the passive conditions rated the device as marginally more useful than those in the active modes, $F(1, 82) = 3.63, p = .06, \eta^2 = 0.04$. There was no statistically significant interaction or main effect of alert for ratings of usefulness. In terms of satisfaction, participants in the visual only groups rated the app as more satisfying compared with those in the audio visual groups $F(1, 82) = 5.39, p = 0.023, \eta^2 = 0.06$. Neither the main effect of mode nor the interaction effect was statistically significant.

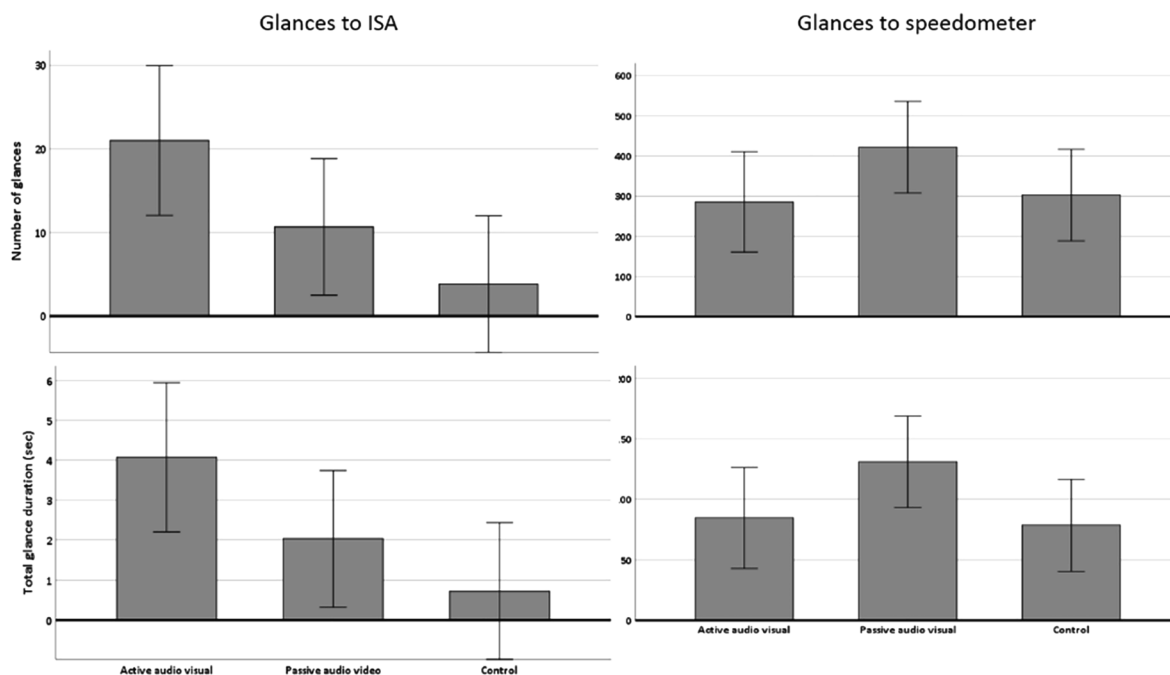


Fig. 9. Participants' mean number of glances (top row) and mean total glance duration (bottom row) at the ISA (left column) and speedometer (right column). Vertical lines represent 95% confidence intervals.

Table 3

The participants' average ratings of the ISA across the four conditions. Data is presented as mean (SD) for the simulator only group.

| Item | Active audio visual (n = 22) | Active visual (n = 22) | Passive audio visual (n = 21) | Passive visual (n = 21) |
|----------------------------------|------------------------------|------------------------|-------------------------------|-------------------------|
| Useful–useless | 1.00 (0.82) | 0.73 (1.23) | 1.14 (0.91) | 1.24 (0.89) |
| Pleasant–unpleasant | 0.32 (0.89) | 0.50 (0.86) | 0.38 (1.28) | 0.86 (1.01) |
| Good–bad | −0.10 (1.02) | 0.41 (0.85) | −0.10 (1.34) | 0.71 (1.06) |
| Nice–annoying | 0.86 (0.89) | 0.73 (1.12) | 1.24 (0.89) | 0.91 (1.14) |
| Effective–superfluous | 0.61 (0.68) | 1.00 (1.07) | 1.14 (0.73) | 1.29 (0.85) |
| Likeable–irritating | 1.00 (0.87) | 1.27 (0.83) | 1.43 (0.60) | 1.20 (0.75) |
| Assisting–worthless | 0.60 (0.91) | 0.68 (0.99) | 1.05 (0.97) | 1.19 (0.81) |
| Desirable–undesirable | 0.09 (1.06) | 0.27 (0.83) | −0.10 (1.00) | 0.62 (1.02) |
| Raising alertness–sleep inducing | 0.41 (0.73) | 0.63 (1.09) | 0.62 (0.86) | 1.00 (1.00) |
| Overall: usefulness | 0.87 (0.66) | 0.89 (0.84) | 1.20 (0.60) | 1.16 (0.77) |
| Overall: satisfying | 0.18 (0.78) | 0.46 (0.75) | 0.50 (0.99) | 0.80 (0.93) |

4. Discussion and conclusions

The aims of the study were to assess (1) how driving performance changed in response to the information provided by the ISA app in different display modes and (2) to assess any distractive effects of the ISA app.

The effects of the ISA app on driving performance were positive; the app resulted in good compliance, with participants' speed choice being close to the posted speed limits along the simulated road. There were no significant differences between the four versions of the app, but all led to better speed compliance than the control (no ISA) condition, particularly for the 60 km/h speed limit. The active/passive and auditory/auditory-visual versions of the app did not differ from one another either in terms of speed compliance or the number of speeding alerts received from the device. These findings support previous reports of the beneficial effects of ISAs in on-road trials (Lai and Carsten, 2012; Warner and Åberg, 2008) and in simulator studies (Whitmire et al., 2011).

We found no evidence that the ISA distracted the drivers, or led to other negative driving-related outcomes. The presence of the speed warnings did not inhibit overtaking, and there was no difference in the number of vehicles overtaken across the groups. Furthermore, participants' lane keeping performance (SDLP) was similar across all ISA modes and the control group. No adverse reactions to any of the hazards were observed for any of the participants as one might have expected if the ISA posed an increased risk due to distraction. In addition, there was no evidence that even the active ISA mode resulted in greatly increased visual load. Across the entire simulated drive the number of glances at the ISA app were few, and although there were more glances at the device in the active version of the system, the absolute number for the entire drive was still very low ($M = 21.0$, $SD = 4.17$). The total time spent looking at the device was also very low (0.40% of the time for the active version), and the average glance duration of 190.24 msec for

this group did not approach the acknowledged upper limit for in-vehicle device distraction of two seconds (NHTSA, 2012). Glances at the ISA app were significantly fewer and shorter than at the vehicle speedometer, which had an overall average glance duration of 281.96 msec. These findings do need to be interpreted with some degree of caution due to the relatively small number of participants in the eye tracking groups.

The current findings, and those of Whitmire et al. (2011), highlight that ISAs appear particularly effective in lower speed limit zones, and it is worth considering why this is the case. In the current study the low speed zone consisted of a section of road with standard dashed white road markings, with a posted speed limit of 60 km/h whilst Whitmire et al.'s (2011) participants negotiated a roadwork site situated on a rural road with a speed limit of 105 km/h. In both cases, other than signage, the appearance of the lowered speed limit zone was the same as the surrounding roads with higher speed limits. Several studies have demonstrated that drivers fail to keep to the speed limit when the look and feel of the road do not match the posted speed (e.g., Charlton and Starkey, 2017a; Goldenbeld and van Schagen, 2007). In part this may be because drivers form mental categories of roads based on how they look, for example, rural roads (as portrayed in the current study) are predominantly categorised by road geometry including curves, intersections, lane separation and road width (Charlton and Starkey, 2017b; Gundy, 1994) and drivers' speed choice is determined by the road category (although speed choice does not always match the posted speed limit). In contrast, when drivers were asked to categorise roads designed according to self-explaining roads principles (i.e., the look and feel of the road matched the posted speed limit), drivers' subjective categorisation of roads matched the formal road classification and the posted speed limits (Kaptein and Claessens, 1998). This clearly highlights the importance of the appearance of the road in communicating speed limits. Findings from the current study suggest that ISAs may be an effective way to assist drivers to maintain a safe speed, particularly on lower speed roads, when the look and feel of the road do not match the posted speed limit.

As noted earlier, there were no significant differences between the four ISA modes (active/passive and visual/audio visual) in relation to speed compliance or distractive effects. Overall the drivers rated the ISA app as useful, particularly those in the passive groups, where the speed limit automatically updated when entering a new speed zone. It remains to be seen however, how often drivers would actually use an ISA app of this type on-road (Jamson, 2006), and how effective it would remain in the longer term, with previous reports suggesting drivers show habituation (or non-compliance) over time (Warner and Åberg, 2008). Similarly, our results may not be generalizable to ISA apps with interfaces that require substantially more driver interaction than our active ISA mode. Another potential limitation of the present study was the younger age of the participants in the eye tracking group. Although this was unintentional, and likely the consequence of excluding participants who wore corrective lenses from this group, it does mean that the visual load data may not have been the same for the full sample. The previous literature on driver distraction, however, suggests that younger drivers are disproportionately susceptible to driver distraction and thus the older participants in the full sample might have been even less likely to spend time looking at the ISA device than the younger eye tracking group (Bingham, 2014; Cassarino, and Murphy, 2018).

In summary, our findings indicate that an ISA app displayed on a mobile phone improved compliance with the posted speed limits during a simulated drive, and did not result in any negative impacts on driver behaviour. This suggests that driver safety apps such as the one tested here, may be an easy way for drivers of older vehicles to realise the safety benefits of associated with new technologies. Although drivers rated the ISA in the current study as useful, one of the greatest challenges may be to persuade drivers to use this type of application every day. ISAs may be particularly useful for drivers travelling to unfamiliar places where speed limits may differ from their expectations and on roads with lower speed limits, where the look and feel of the road do not match the posted speed limit.

Acknowledgements

The authors would like to thank all those who took part in this study, our research assistants who provided invaluable help with data collection and data entry, members of the steering group (Dr Fergus Tate, Shelley Easton, Ian McGlinchy, Shannon van Lier, and Nils van Lamoën), and research consultants (Professor David Crundall and Professor Samantha Jamson). The study was funded by New Zealand Transport Agency (TAR16_18).

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