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Identifying the distracting aspects of electronic advertising billboards: A driving simulation study

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ABSTRACT

The aim of the study was to investigate the impact of digital billboards on driving performance and visual attention. The impact of dwell time, location and content of digital billboards on driving behaviour was also examined. A 3 × 2 × 2 × 2 experimental study was undertaken using a laboratory driving simulator and data analysed using factorial four-way analysis of variance. A total of 96 participants completed the study, ranging in age from 18 to 76 years. On sections of roads containing billboards, participants drove at lower mean speeds ($p < 0.001$), had more speed variability ($p < 0.001$), more variability in lane position ($p < 0.001$), more time spent at high risk headway < two seconds ($p = 0.013$), more time spent at high risk headway < 0.25 s ($p = 0.002$) and had more visual fixations ($p = 0.01$), compared to control sections of road with no billboards. Billboards with simple (versus complex) content presented at a long dwell time (60 s versus 40 or 20 s) had the least negative impact on driving outcomes. Billboards with complex content had similar negative effects on driving, regardless of dwell time. In addition, post-mounted roadside billboards (versus bridge mounted) with 60 s dwell times had the least negative impact on driving. While the presence of digital billboards negatively affected driving performance, simple billboard content and longer dwell times were safer. The results of the study will assist in the development of evidence-based guidelines for digital billboards.

1. Introduction

Driver distraction is now accepted as an important contributor to road crashes (Road Safety Commission, 2019). While it is difficult to obtain accurate estimates of the exact contribution of distraction to crashes, it is conservatively estimated that approximately 30 % of all crashes involve driver distraction (Wang et al., 1996) with concern that roadside advertising, in the form of digital billboards, may be a significant component of the distraction from outside the vehicle.

A recent review found that roadside advertising impacts on driver behaviour but that this impact may vary according to the characteristics of the driver and the characteristics of the advertising (Oviedo-Trespalacios et al., 2019). To date, several simulator and on-road studies have examined the impact of billboards on various measures of driving performance. For example, a simulator study by Young et al. found that the presence of advertisements on rural roads increased the amount of time drivers spent outside of designated lanes by four times (Young et al., 2009). This finding was supported by another small simulator study (Bendak et al., 2010). In terms of the impact of billboards on speed, studies to date have reported conflicting results. While two simulator studies reported decreased mean speed in the presence of billboards (Edquist et al., 2011; Horberry et al., 2006), another simulator study and an on-road study reported no significant impact on speed or speeding (Lee et al., 2003a, 2003b; Bendak et al., 2010). An additional on-road study found significantly increased variation in speed in the presence of billboards (Lee et al., 2007). Conflicting results have also been reported regarding the impact of billboards on headway (distance to the vehicle in front). While a simulator study reported that participants travelled significantly closer to the lead vehicle in the presence of billboards (Milloy and Caird, 2011), an on-road study found no association between billboards and headway (Smiley et al., 2005). It is likely that these conflicting findings are due to the examination of the effect of different types of billboards, under different conditions, among different drivers.

Roadside advertising in the form of digital billboards are becoming more commonly used next to Australian roads. However, while there is now a substantial body of evidence that digital billboards have the potential to be distracting (Austroads, 2013); (Oviedo-Trespalacios et al., 2019), the research to date has not been designed specifically to inform road authority guidelines. As a result, it is unclear, for example, exactly how much more distracting a 20 s dwell time (duration of message display) is than a 40 s dwell time. This issue is critical because

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Fig. 1. The driving simulator.

while the outdoor advertising industry prefers shorter dwell times, these shorter dwell times expose the traffic stream to more image changes over time, and is likely that the image change is a critical aspect of the attention capturing effect of a digital billboard (Austroads, 2013). Similarly, many other questions for road authorities, such as the relative impact of placement and content differences of digital billboards remain unexplored. Therefore, the aim of this study is to investigate the impact of digital billboards on driving performance and visual attention using a driving simulator. The relative impact of different values of dwell times, location and content of digital billboards and their interactions was also examined. The results from the current study will provide important evidence to develop evidence-based guidelines for digital billboards to reduce distraction.

Specific objectives of the study were to:

1 Assess driving performance specifically, speed, lane keeping, high

Fig. 2. Tobii Pro eye tracker.

risk headway and very his risk headway, in the presence of digital billboards with varying dwell times, location and content.

2 Assess the effect of digital billboards on gaze fixation.

3 Identify values for dwell times, location and content of digital billboards that create problematic levels of driver distraction.

2. Materials and methods

2.1. Study design

A 3 × 2 × 2 × 2 experimental driving simulation study was undertaken to manipulate the following aspects of digital billboards in a safe and experimentally controlled environment. These included

- Dwell time (3 levels – "20 s", "40 s" and "60 s")
- Location (2 levels - bridge; i.e. "*directly overhead*" versus "*post-mounted on the side of the road*")
- Design content (categorized as either a "*simple*" or "*complex"*)
- Billboard ("*no billboard*" and "*billboard*")

The term 'dwell time' is used in this paper to mean 'the duration of the display of a particular advertisement'. We use this term throughout as it is the term used by road authorities in their guidance documents and by the outdoor advertising industry. These three dwell times were chosen because they represent the three most likely options according to the policy document of the local road authority.

2.1.1. Sample size and recruitment strategy

A convenience sample of Perth-based participants were recruited from universities, social media and newspaper advertisements. Inclusion criteria stipulated that each participant had been driving a motor vehicle for at least one year; drove at least three times a week; lived in the Perth metropolitan area, were able to attend a driving simulator assessment and had not moved interstate or from overseas in the past twelve months. Exclusion criteria included those with a diagnosis of dementia, Parkinson's disease, were wheelchair-bound; did not speak English, had a history of nausea and/or vomiting; a recent head injury and/or a history of seasickness.

2.1.2. Data collection

Each participant completed a researcher-administered questionnaire using Qualtrics which is an online survey software program. A driving simulator assessment was also undertaken by each participant. An information sheet was provided to all participants and informed consent was obtained by the researcher. The complete experiment took approximately one hour.

A small pilot study was undertaken to confirm content validity and reliability (test-retest), length and appropriateness of the questionnaire and driving simulator tasks. The questionnaire was reviewed by a panel of road safety, human factors and engineering experts and modifications were made accordingly.

Participants' socio-demographic data including age, sex, marital status, education, co-morbid medical conditions, current prescribed medications, and the number of crashes and demerit points/infringement notices incurred over the previous five years were collected.

The driving simulator consists of a fully functioning Kia sedan with working controls and instruments (car and visual system) and is enclosed to remove any outside distractions. It is mounted on a six degree of freedom motion system to recreate driving inertia forces and includes a 360-degree projector wrap-around visual system, allowing for the use of vehicle mirrors. Images are displayed in full high definition resolution of 1920 × 1080 pixels per channel and updated at a frame rate of 120 Hz. The OKTAL SCANeRTM studio software package was used to simulate the driving experience and record the performance data (Fig. 1).

The Tobii Pro Glasses 2 is a wearable eye tracker which contains four eye cameras. It has a variety of prescription lenses which can accommodate participants who wear prescription glasses. Participants wore the eye tracker while driving in the simulator to collect data on visual scanning behaviour throughout the scenario (Fig. 2).

2.2. Scenario development

Twelve scenarios were simulated which consisted of a combination of three levels of dwell time (20 s, 40 s and 60 s), two different billboard locations (overhead on a bridge versus post mounted on the left side of the road) and two billboard content designs (complex versus simple). Note that participants did not view the same advertisement necessarily for the full dwell time duration. As explained above, this manipulation mimics the real-world situation with interest centring on relative differences in exposure to message change frequency associated with different dwell times. An example of one of the scenarios is shown in Fig. 3.

When selecting the billboards to include in the driving scenarios, 35 typical Australian billboards were reviewed by ten road safety and human factors experts. They ranked the level of complexity of the billboard content on a scale of one to five. This ranking was based on the individual's perception of the level of complexity of the information presented. The six billboards with the lowest ranking were included in the study and classified as *'simple'* billboards. The six with the highest ranking were also included and classified as *'complex'*. Fig. 3 presents an example of *'simple'* billboard content.

A section of the freeway which was associated with each billboard was matched for the same road and traffic conditions except that the billboards were not present (control section). To ensure that the driving scenario was sufficiently challenging to the participant, traffic was included around the driven vehicle.

2.3. Familiarisation and driving procedure

Participants were given the opportunity to drive a five-minute practice circuit in the driving simulator to ensure that all participants met a minimum standard of proficiency (for example: able to use turn signals; side mirrors; accelerator and brake pedal). Participants were also introduced to the Tobii eye tracker, which was adjusted for comfort and calibration on the forward scene.

Participants were not told in advance that the study was investigating distraction from billboards, they were simply told it was a freeway drive and to behave as they normally would, adhering to signage and speed limits. One 100 km/hr speed sign was placed at the beginning of each of the twelve driving scenarios Each participant '*drove*' through one driving scenario in daylight conditions which consisted of three randomly selected billboards with randomly allocated dwell times, location of billboard (overhead on bridge or post mounted on the side of the road) and complexity (simple or complex) of billboard during the day time. For each billboard, a section of the freeway was matched for the same road and traffic conditions except that the billboard was not present. These served as 'control' sections of freeway. For each driver, observations were made for three billboards and three

Fig. 3. Example of an overhead billboard on a bridge.

control sections of road, totalling 576 observations. It took approximately ten to fifteen minutes to complete the drive depending on the speed of the participant.

2.4. Driving simulator and eye tracking data

Driving simulator performance data were automatically recorded by the OKTAL SCANeRTM studio software which records data at a rate of 20 Hz. For the assessment of driving performance, evaluative measures of longitudinal and lateral control in the vicinity of the billboard (the 400 m on approach to the billboard) were used. Longitudinal control measures speed, standard deviation of speed and headway. Headway (measured in seconds) refers to distance to the motor vehicle in front. A two second or less distance to the car is front is considered to be unsafe. A measure of high-risk headway (< 2 s) and very high-risk headway ($< .250$ s) were obtained from the driving simulator. As the road sections were fairly straight, mean lateral shift and standard deviation of lateral shift were chosen as a measure of lateral control.

Participants wore the eye tracker while driving the simulator which recorded eye movement, and the visual measurements "*mean gaze position*" and "*standard deviation (SD) of gaze position*" were calculated. Mean gaze position is a measure of the tendency in which you look to the left (-) or the right (+). The standard deviation of gaze position is a measure of visual fixation. It is the standard deviation of the directions of all horizontal glances while in the vicinity of the billboard. The higher the standard deviation the less time the eye fixates on a "spot" to the left or the right whereas the lower the standard deviation the longer time the eye is fixating on a "spot". These two measures were chosen because it was possible to measure and compare them with control sections of road where there was no billboard.

2.5. Statistical analysis

Descriptive analyses were undertaken to describe the demographic and driving profile of the sample. A factorial four-way analysis of variance (ANOVA) was undertaken to determine if an interaction effect existed between the independent variables for each of the driving simulator performance and visual measures. The four factors included dwell time (20 s, 40 s and 60 s), location (overhead billboard, post mounted on the side of the road billboard), content (simple billboard, complex billboard) and billboard (billboard, no billboard). Post-hoc tests using the Sheffe's test were undertaken when a significant main effect or interaction effect was found in the overall ANOVA. Shapiro-Wilk and Levene's test were used to evaluate the assumption of normality and homogeneity of variances respectively. Significant effects were reported at $p < 0.05$.

3. Results

3.1. Characteristics of the sample population

The final sample consisted of 96 drivers which represented a total of 576 observations. During the driving simulation five drivers experienced motion sickness and were replaced with another participant. This sample size was sufficient to detect a difference at alpha of 0.05 with at least 80 % power.

The mean age of the drivers was 33.7 years (SD = 15.1) ranging from 18 to 76 years with a median age of 28.5 years The 17–24 years age group had the highest number of participants with 36 (37.5 %), followed by the 25–40 years age group with 34 participants (35.4 %). Approximately 10 % of the sample was aged 60 + . The majority of the participants were male (n = 66, 68.8 %), single (n = 45, 46.9 %), had a university degree (n = 85, 88.5 %), were born in Australia (n = 64, 66.7 %) and English was the predominant language spoken at home (n = 88, 91.7 %). The majority (70.8 %) of participants rated their driving as good, and 19.8 % as excellent. The mean number of years of driving experience since obtaining a driver's license was 16 (SD = 15.1). Approximately 53.1 % drove on average seven days a week. Twenty percent of participants (n = 20) had undergone additional driver training/ qualifications.

3.2. Driving performance and visual measures

3.2.1. Mean speed

Mean speed showed a significant main effect in the vicinity of a billboard ($F(1,552) = 138.862$, $p < 0.001$). The average speed was lower when the vehicle was travelling through a section of the road with a billboard (mean 79.457, SD = 0.944) compared to no billboard (mean 94.905, SD = 0.944). A significant three way interaction for mean speed was found for billboard, content and dwell time ($F(2, 552) = 3.307$, $p = 0.037$). A significant difference in the mean speed between a simple billboard with a dwell time of 40 s and a simple billboard with a dwell time of 60 s ($p = 0.03$) was found based on the results of the Scheffe test, with participants driving significantly faster in the vicinity of the the billboard at 60 s compared to 40 s (Fig. 4).

3.2.2. Speed Variability (standard deviation (SD) of speed)

There was a significant main effect for billboard and no billboard (F

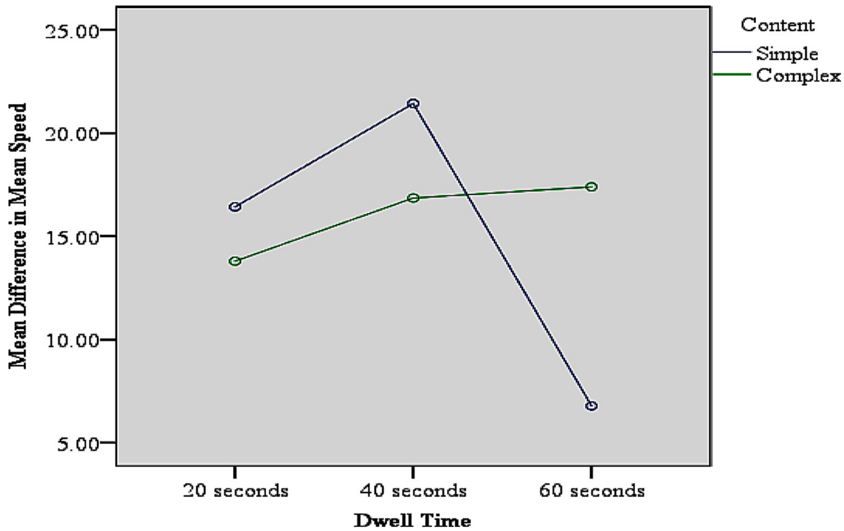

Fig. 4. Interaction between billboard content and dwell time for mean speed.

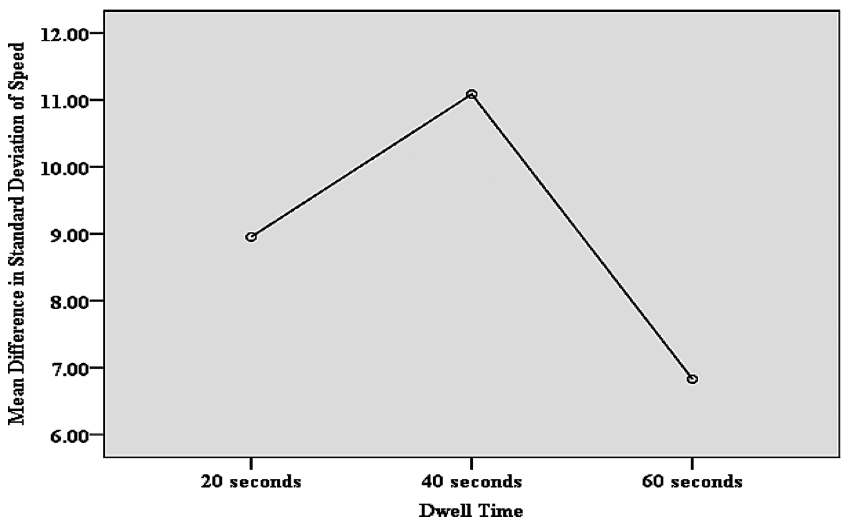

Fig. 5. Interaction between dwell time and billboard for SD of speed.

(1,552) = 212.46, $p < 0.001$) with more variability in speed when driving in the vicinity of a billboard (mean = 10.50, SD = 0.44) compared to no billboard (mean = 1.54, SD = 0.44). There was also a significant two way interaction between billboard and dwell time (F (2,552) = 3.99, p = 0.019). A significant difference in the variability of speed between a billboard with a dwell time of 40 s and a billboard with a dwell time of 60 s was found based on the results of the Scheffe test, with participants exhibiting less speed variability in the vicinity of the billboard at 60 s compared to 40 s (Fig. 5).

There were *three* significant three-way interactions for speed variability. First, there was a significant three way interaction between billboard, content and dwell time (F(2, 552) = 4.11, p = 0.02). The Scheffe test showed a significant difference in the variability of speed between a simple billboard with a dwell time of 40 s and a simple billboard with a dwell time of 60 s (p = 0.02), with the 60 s dwell time having less speed variability than the 40 s dwell time (Fig. 6).

The second significant three way interaction was between billboard, content and location (F(1, 552) = 4.53, p = 0.03). A crossover interaction was found between a billboard post-mounted by the side of the road and a billboard on an overhead bridge with the impact on speed variability different depending on the content of the billboard ($p > 0.05$). This crossover interaction showed that while simple content had less negative impact when presented on an overhead bridge structure, the opposite was true for complex content (Fig. 7).

The third significant three way interaction was between billboard, dwell time and location (F(2, 552) = 3.23, p = 0.04). (Table 4). The Scheffe test showed a significant difference in the variability of speed between a billboard post-mounted by the side of the road with a dwell time of 40 s and a post-mounted billbords with a dwell time of 60 s (p = 0.04), with the 60 s dwell time showing less variability than the 40 s dwell time (Fig. 8).

3.2.3. Lane positioning

There was a significant main effect for billboard on the standard deviation of lateral shift (F(1,552) = 11.927, p= < 0.001). More variability in lane position was found when the vehicle was travelling through a section of the road with a billboard (mean 0.221, SD = 0.140) compared to no billboard (mean 0.181, SD = 0.128). However, mean lateral shift was unaffected by the presence of billboard (p = 0.07).

3.2.4. High risk headway (< 2 s) and very high-risk headway (< .250 s)

A significant main effect for billboard (F(1, 552) = 7.028, p = 0.013) was found for time spent at high risk headway < 2 s. More time was spent at high risk headway < 2 s when the vehicle was in the vicinity of a billboard (mean 3.757 s, SD = 5.974) compared to no

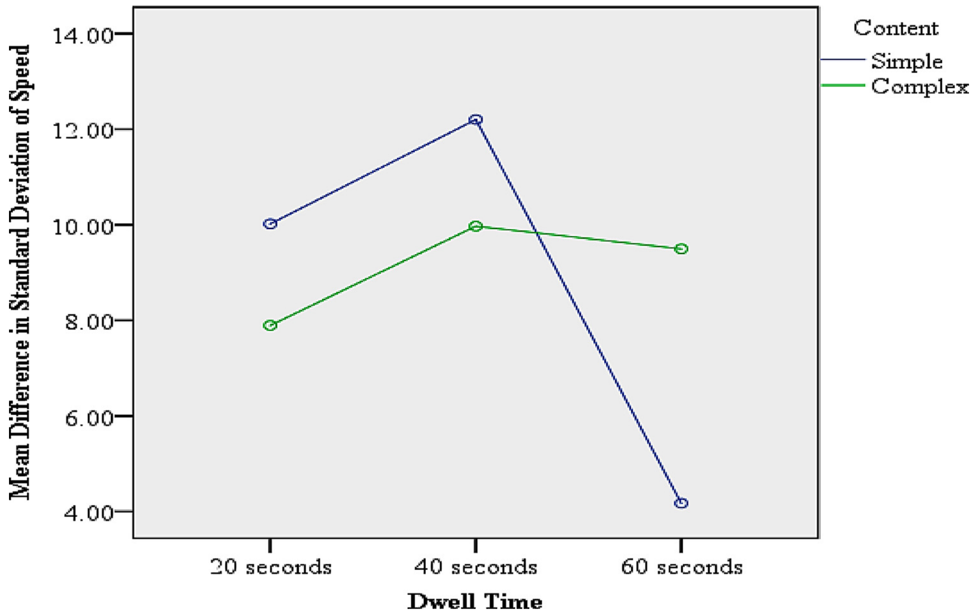

Fig. 6. Interaction between billboard content and dwell time for SD of speed.

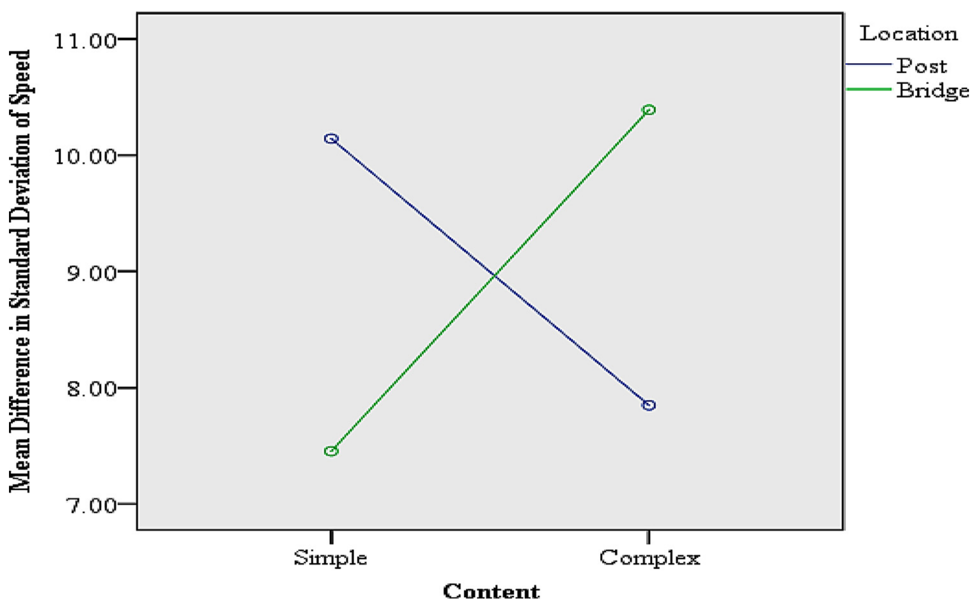

Fig. 7. Interaction between billboard location and content for SD of speed.

billboard (mean 2.534 s, SD = 5.020).

A significant main effect for billboard ($F(1, 552) = 9.641$, $p = 0.002$) was also found for time spent at very high risk headway < .250 s. More time was spent at very high risk headway < .250 s when the vehicle was in the vicinity of a billboard (mean 0.426 s, SD = 2.134) compared to no billboard (mean 0.032 s, SD = 0.089).

3.2.5. *Mean gaze position and standard deviation (SD) of gaze position*

There were no significant main effects ($p = 0.041$) or any interaction effects between billboard, location, content and dwell time ($p = 0.52$) on mean gaze position. However a significant main effect for standard deviation of gaze position (visual fixations) ($F(1, 552) = 7.57$, $p = 0.01$) was found with more fixations reported in the vicinity of a billboard (mean = 0.098, SD = 0.041) than when no billboard was present (mean = 0.108, SD = 0.041).

4. Discussion

This study used a driving simulator and eye tracker to investigate the impact of digital billboards on driving performance and visual behaviour. This allowed a unique examination of the influence of a number of billboard characteristics (dwell time, billboard complexity, and billboard position) and their interaction. Several studies have reported on the external validity of driving simulators and have found that behavioural changes seen in the simulator translate to the real world, and thus can be considered representative of an analogous change in real world driving performance (Godley et al., 2002; Lee et al., 2003a, 2003b, Meuleners and Fraser, 2015).

The consistent finding from this study is that the presence of digital billboards (compared to no billboard) adversely affected driving performance across most measures including mean speed, speed variability, variability in lane position, high risk headway, very high risk headway and visual fixations. While reductions in mean speed may

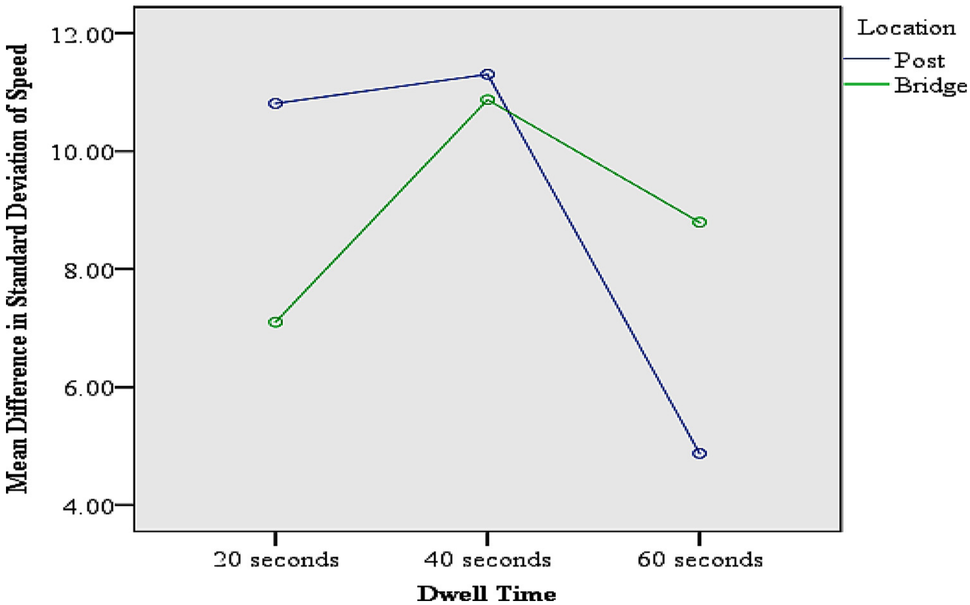

Fig. 8. Interaction between billboard location and dwell time for SD of speed.

suggest safer driving, this study also found significantly more speed variability in the vicinity of billboards. It is therefore likely that the speed reduction and variability was due drivers' attention being engaged by the billboard with less attention directed towards speed control (Chattington et al. 2010). Increased variability in lane position in the vicinity of billboards again suggests driver distraction and this supports the results of previous studies (Young et al., 2009; Bendak et al., 2010). Drivers also spent more time at high risk headway < 2 s and very high-risk headway < 0.25 s when in the vicinity of billboards versus an area with no billboards. It is recommended that drivers maintain a minimum distance of two seconds to the vehicle in front. This is based on the reaction time of drivers as the majority can react within two seconds in order to prevent a rear-end collision or multiple collision (Lamm et al., 1999). The finding that the presence of a billboard increased the amount of time drivers spent at high risk and very high-risk headways to the vehicle in front, suggests that billboards could increase crash risk. Finally, while the presence of billboards did not significantly impact on mean gaze position, drivers tended to fixate on one location significantly more when in the vicinity of a billboard. This could impact on driver safety since previous research found that off-road glances greater than two seconds doubled the risk of near-crashes and crashes (Klauer et al., 2006).

The degree of the effect of billboards on driving performance varied depending on the dwell time, complexity of the content and location of the billboard that drivers were exposed to. There was significantly less variability in speed for a dwell time of 60 s than for 40 s and 20 s. While complex content had a similarly negative impact at all dwell times and simple content had a similarly negative impact at 20 and 40 s; at 60 s the negative impact of simple content declined significantly and almost back to baseline. This strongly suggests, at least within the parameters and assumptions of this study, that only simple content presented at a long (60 s) dwell time may not influence driving performance significantly.

Interestingly, location had an analogous effect to complexity on modifying the degree of driving impairment. While bridge mounted billboards resulted in a similar degree of impairment across the three dwell times and post mounted billboards were similar for 20 and 40 s dwell times; at the 60 s dwell time, impairment from post mounted billboards declined significantly to near baseline levels. This strongly suggests, at least within the parameters and assumptions of this study, that only post mounted material presented at a long (60 s) dwell time may not influence driving performance significantly.

These findings are congruent with recommendations that dwell times should be as long as possible (Austroads, 2013). In addition, the results suggest an unexpected conclusion that in some situations billboards mounted on the side of the road may be safer than billboards directly over the road. In general, it has been assumed that billboards directly over the road should be safer because they do not require the driver to shift their gaze from the forward roadway. It should be noted however that the study also found a cross over interaction between location and complexity suggesting that complex material had a greater negative impact when bridge-mounted, while simple material had a greater negative impact when post-mounted. Thus, the conclusion that billboards post-mounted on the side of the road are safer needs to be tempered by the complication that this may only be true for complex content. Perhaps complex content on roadside billboards simply requires too much attention and eyes off the forward roadway time and so drivers self-regulate and engage less with the billboard. On the other hand, when the billboard is directly in front perhaps drivers feel safer allocating more attention to it and hence their driving performance is more negatively affected. Whatever the explanation for this result, it is consistent with the other results showing that more complex content has a more negative impact on driving performance (Beijer, 2002; Zhang et al., 2013).

A strength of the study was the large sample size which had enough power to detect difference between driving situations. In addition, the study utilized billboards that are currently used on Australian roads, consisting of simple images as well as more complicated images, at two different positions, with three different dwell times. However, there were several limitations to this study which are inherent in driving simulation studies. For instance, it is not possible to say that the findings of this simulator study transfer to real world driving. The simulated images on the billboard do not offer the same resolution as real world billboards so there may have been some issues regarding the legibility of the billboards that could have affected visual experience and driver behaviour. However, it is worth noting that an (unpublished) evaluation for a state road authority, of a large format digital billboard using video analysis of vehicle movements on approach to the sign, obtained similar results to the current study. Longer dwell times had a less severe negative impact on driver performance that shorter dwell times (Cunningham et al., 2016). Due to the complexity of the experimental study design with four factors, participant characteristics such as age and gender were not considered in the analysis but should be included in future research as these factors may modulate the degree of driver impairment caused by billboard distraction (Edquist et al., 2011).

5. Conclusion

Drivers will continue to be exposed to an increasing volume and range of road side advertising due to the power of the advertising industry. Therefore, it is crucial for road safety researchers to try to identify billboard characteristics that are the most distracting. The study found that digital billboards adversely affected driving performance across the majority of measures including mean speed, speed variability, high risk headway, variability in lane position and visual fixations. Longer dwell times generally had less negative impact than shorter dwell times with only simple content presented at a long (60 s) dwell time and post-mounted billboards presented at a 60 s dwell time not adversely affect driving performance. These results will assist in the development of evidence-based guidelines for digital billboards.

reference

Divekar et al. (2012).

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CRediT authorship contribution statement

Lynn Meuleners: Conceptualization, Funding acquisition, Formal analysis, Investigation, Methodology, Project administration, Writing - original draft, Writing - review & editing. **Paul Roberts:** Conceptualization, Funding acquisition, Investigation, Methodology, Writing - original draft, Writing - review & editing. **Michelle Fraser:** Methodology, Formal analysis, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aap.2020.105710.

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