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Driving simulator study on the influence of digital illuminated billboards near pedestrian crossings

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ABSTRACT

Objective: To evaluate the effect of display time and distance of digital illuminated billboards near a pedestrian crossing on glance and driving behavior.
Background: Several functional characteristics and placement conditions of digital billboards influence glance and driving behavior.
Method: Forty-one participants drove seven different routes (3.8–5.2 km) in a driving simulator. We performed a repeated measures ANOVA with presence of billboard, display time of the message (3 s, 6 s and 15 s), distance from a pedestrian crossing (41 m and 65 m) and road environment (transition road to a built-up area and retail zone) as the manipulated conditions in a randomized order.
Results: Shorter display times and retail zone resulted in a significantly higher number of eye glances towards the digital billboard. Participants reported a significantly higher mental workload and a lower estimation of personal driving performance in the presence of a digital billboard. Scenarios with a digital billboard resulted in a somewhat higher approaching speed towards the pedestrian crossing with the minimum approaching speed reached closer to the crossing. The first time a pedestrian crossed the road, reaction time to the crossing pedestrian was higher in presence of the digital billboard (this was not tested statistically).
Conclusion: The presence of a digital billboard, especially with short display time, leads to visual distraction, which has a negative impact on driving behavior and traffic safety.

1. Introduction

1.1. Advertising signs/digital billboards

Despite obvious financial benefits of (digital) advertising signs, the downside of roadside advertisement is driver distraction. Roadside advertising attracts visual attention and cognitive central processing, so billboards would be expected to cause task interference with driving tasks that require visual fixation and central processing (Wickens, 2008). Given that people have limited attentional resources, if attention is pulled away from the driving task towards a roadside advertisement, this may leave insufficient attentional capacity for the adequate execution of the driving task (Wickens, Hollands,

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Banbury, & Parasuraman, 2015). However, a direct causal relationship between distraction from advertising billboards and road crashes is difficult to prove (SWOV, 2012).

To investigate the effects of roadside advertising, different studies focused generally on three outcome measures: glance behavior, cognitive factors (e.g. driver workload), and driving behavior (e.g. driving parameters and crashes). Different eye movements studies while driving (Beijer, Smiley, & Eizenman, 2004; Belyusar, Reimer, Mehler, & Coughlin, 2016; Crundall, Van Loon, & Underwood, 2006; Garrison & Williams, 2013; Lee, McElheny, & Gibbons, 2007; Misokefalou, Papadimitriou, Kopelias, & Eliou, 2016; Smiley et al., 2005; Stavrinos et al., 2016) provide evidence that billboards may capture drivers' visual attention and hold it for some period. An overall conclusion is that the presence of a digital billboard results in a higher mental workload (Chattington, Reed, Basacik, Flint, & Parkes, 2009; Edquist, Rudin-Brown, & Lenne, 2009; Young & Mahfoud, 2008). Backer-Grøndahl & Sagberg (2009) have shown that distraction related to advertising billboards increases crash risk by a factor of 17 (self-reported behavior), and Gitelman, Zaidel, & Doveh (2012) found a statistically significant increase of crash rate near billboards (before-and-after study). Other studies (Izadpanah, Omrani, Koo, & Hadayeghi, 2014; Smiley et al., 2005; Yannis, Papadimitriou, Papantoniou, & Voulgari, 2013) have suggested that the contribution of roadside advertising to crashes is likely to be relatively small or even non-existent (before-and-after study). On the basis of the results it cannot be concluded that (digital) billboards increase crash risk nor can it be concluded that they have no effect on crash risk at all.

1.2. Pedestrian crash data analysis

Pedestrian fatalities greatly vary among the different countries in the European Union. The lowest rate of pedestrian fatalities per million inhabitants (year 2014) is in the Netherlands (3) and Denmark (4), while the highest is in Lithuania (37) and Latvia (35) with an average of 11 for the European Union (European Road Safety Observatory, 2017). Considering all fatalities (year 2014; excluding Lithuania), pedestrians have a share of 21% (European Road Safety Observatory, 2016). Compared with other modes of transport, pedestrians have only a decrease of 35% during the decade 2005–2014 (while the overall average decrease in number of fatalities in the EU is 42% (European Road Safety Observatory, 2016). Speeding, drink-driving, drug-driving and distracted driving are risk factors that contribute to pedestrian fatalities (WHO, 2015).

1.3. Distraction and (in)attention

Driving a car requires substantial cognitive effort and attention (Borghini, Astolfi, Vecchiato, Mattia, & Babiloni, 2014), and distraction is one of the main challenges. A recent overview of the relevant literature reveals that distraction is likely to be a contributing factor in 10–30% of all European road accidents (European Commission, 2015). Although distraction receives much attention, a uniform definition is still lacking (Hedlund, Simpson, & Mayhew, 2006; Lee, Young, & Regan, 2008). According to Regan, Hallett, and Gordon (2011) distraction in driving always comprises the following: (1) diversion away from (safe) driving; (2) attention diverted towards a competing activity inside or outside the vehicle, which may or may not be driving related; (3) the competing activity may or may not compel or induce the driver to divert his attention towards it; and (4) there is an implicit or explicit assumption that safe driving is adversely effected. A distinction is made between visual distraction (e.g., looking away from the roadway), auditory distraction (e.g., responding to a ringing cell phone), biomechanical distraction (e.g., manually adjusting the radio volume), and cognitive distraction (e.g., being lost in thought) (Ranney, Mazzae, Garrott, & Goodman, 2010).

For (in)attention as well, there is no uniform definition (Talbot, Fagerlind, & Morris, 2013). While some definitions are confusing due to (partial) overlap with distraction, others clearly distinguish from distraction by referring specifically to driver states (e.g. mind-wandering or drowsiness). Inattention simply relates to not paying attention to activities deemed necessary for safe driving with distraction possibly resulting in driver inattention. However, inattention is not necessarily the outcome of distraction (Regan & Strayer, 2014; Regan et al., 2011).

1.4. Aim

The SEEV model (Wickens, Goh, Helleberg, Horrey, & Talleyr, 2003; Wickens, Helleberg, Goh, Xu, & Horrey, 2001) is a model of scanning behavior describing the probability that a given area of interest will attract attention. SEEV refers to the Salience, Effort, Expectancy, and Value associated with a particular area of interest (e.g. billboard). Salience will refer to the physical properties of a billboard while effort will refer to both the effort involved in reallocating attention to the billboard and to the current mental workload. Expectancy will refer to the expectancy of gaining information from the message of the billboard and value will refer to an objective measure of the value or cost of processing or failing to process the information of the message of the billboard. Thus, it is clear that not all objects or billboards will attract the same amount of attention. A literature review (Brijs, Brijs, & Cornu, 2014) on the impact of outdoor (digital) advertising billboards came to the conclusion that the effect relates to several functional characteristics and placement conditions such as panel location, position, size, and luminance level, and, message-related factors such as type, content, complexity, display time, and transition speed. Another conclusion was that there are no uniform guidelines.

This driving simulator study focusses on two characteristics of digital illuminated billboards: display time of the message (also called cycle time or message duration; i.e. the time that one message is visible) and location of a digital billboard. Various countries currently adopt different standards, guidelines and regulations with respect to practical or legislative issues related to billboards. In the Netherlands, a minimum display time of 6 s has been formulated (Merkx-Groenewoud & Perdok, 2011; Theeuwes, 2008) while in Flanders, display time is set at 30 s (Agentschap Wegen en Verkeer, 2015). Even though display times also differ between the different states in the US with display times from 4 up to 10 s, the majority of them use 8 s (Farbry, Wochinger, Shafer, Owens, & Nedzesky, 2001; FHWA, 2007). Smiley et al. (2005) concluded that there are large differences in driver distraction depending on the placement and the environment in which the sign is seen. Some countries prescribe minimal distances or even prohibit billboard installation nearby locations where increased attention is needed (Farbry et al., 2001; Merkx-Groenewoud & Perdok, 2011). This study wants to give scientific evidence-based guidelines related to message duration and the location of digital billboards.

2. Method

2.1. Participants

Forty-one participants were recruited by means of social media, phone calls, flyers, etc. Six participants were excluded, including two outliers (i.e. abnormal speed behavior) and four participants who suffered from simulator sickness. Hence, the available sample consists of 35 participants (19 males and 16 females; age from 22 to 66 years; mean age 39 year; *SD* = 13.1 year). All had a valid car driving license (range from 3 to 42 years; mean 18.7 years; *SD* = 12.8 years) and normal or corrected-to-normal vision. Fifty-one percent of the participants drove more than 15,000 km a year, which is in line with the Belgian average mileage driven (Kwanten, 2016).

The ethical review committee of Hasselt University vetted and approved the study protocol.

2.2. Driving simulator and eye tracker

We used the fixed-base NADS MiniSim™ (version 2.0) driving simulator. The simulated vehicle dynamics were visual and audible, not kinesthetic. The mock-up consisted of a force-feedback steering wheel (Logitech G27) and pedals. Drivers used the automatic gearbox and had full control over their vehicle. We displayed visuals on a 140° screen by means of three TV screens offering a total resolution of 4800×1024 pixels and a 60 Hz refresh rate. The speedometer and tachometer appeared on a fourth screen at their habitual dashboard location. We collected data at frame rate. We recorded eye movements with an eye tracking system, FaceLAB 5.0, and conducted analysis with EyeWorks™ (see Mollu, Cornu, Declercq, Brijs, and Brijs (2017) for a detailed description). To minimize the potential occurrence of simulator sickness, we set the room temperature of the driving simulator lab below 21 °C (Fisher, Rizzo, Caired, & Lee, 2011, pp. 14–17).

2.3. Design and scenarios

We manipulated in every scenario the following two characteristics of the digital billboard: 'display time' (3 levels) of the graphical message (advertising) and 'prior distance from a pedestrian crossing' (2 levels). Other characteristics such as installation angle (90°), distance between ground level and bottom-side of billboard (3 m), surface area of billboard (5 m^2), weather conditions (sunset), and transition time of the messages (0.1 s) were kept similar across all conditions. Sunset weather condition was chosen because this is a compromise between daytime (high traffic volume and a low contrast between billboard and surrounding) and night (low traffic volume and a high contrast between billboard and surrounding). The content of the different messages was more or less the same and consisted of a commercial picture and changed randomly (see Fig. 1). As indicated in the introduction, there is no internationally uniform standard for display time. Therefore, we manipulated this factor at three levels: 3 s (short), 6 s (medium) and 15 s (long). The distance of the digital billboard prior to the pedestrian crossing was based on the stopping distance and guidelines regarding the cut-off distance where drivers will stop reading a message (Department for Transport, Department for Regional Development (Northern Ireland), Scottish

Fig. 1. Visualization of a billboard and a pedestrian crossing.

Table 1
Overview of design.

	Display time 3 s	Display time 6 s	Display time 15 s
Distance 41 m	Scenario 2	Scenario 4	Scenario 6
Distance 65 m	Scenario 3	Scenario 5	Scenario 7

Scenario 1: reference scenario without a digital billboard present (no display time and no distance).

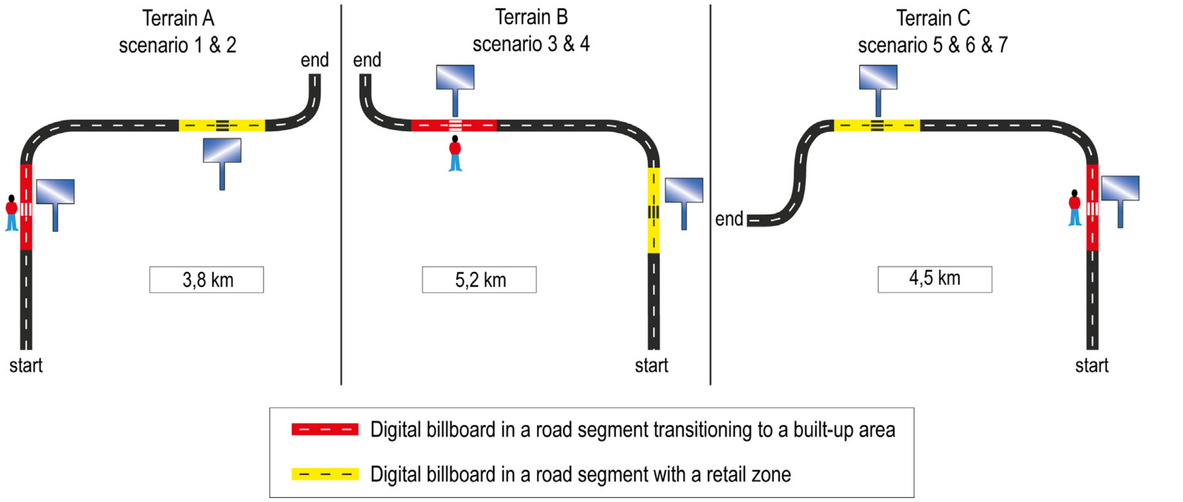

Fig. 2. Three different terrains that were used for the scenarios.

Government, & Welsh Government, 2013). This results in a minimum distance of 41 m prior to the pedestrian crossing. A higher value of 65 m was chosen, however, this is still relatively close to the pedestrian crossing (see Table 1).

Every scenario (3.8–5.2 km) represented a typical Flemish single lane two-way road with opposing traffic and some cyclists on a cycle path. At the beginning of a trip, the car was parked and drivers are instructed to accelerate. After 30 m, a speed sign of 70 km/h appeared. A small part of every scenario was situated inside an urban area where the speed limit was 50 km/h. The road was accompanied with a separated bicycle path on both sides. To eliminate learning effects, we used seven scenarios in the simulation at three different terrains with curves, hills and intersections (terrain A was used for scenario 1 and 2; terrain B for scenario 3 and 4; and terrain C for scenario 5, 6 and 7) (Fig. 2; remark: scenario 1 used the same terrain as scenario 2 but there was no billboard present while there was one present in scenario 2).

Each of the seven scenarios contained one specific road segment transitioning to a built-up area and one segment with a retail zone and these were the same for every scenario. In these two segments, we located a digital billboard 6 m to the right from the middle of the right lane and at a predefined distance prior to an indicated pedestrian crossing. The pedestrian crossing, which was equipped with markings and signs, served as a location where increased attention is needed. In order not to influence the results, 400 m prior to the digital billboard the road geometry and environment were kept identical across different scenarios. Furthermore, to stimulate uniform speed across participants, 400 m prior to the billboard we located a speed limit sign of 70 km/h.

A pedestrian was programmed to always cross the road at the pedestrian crossing located in the road segment transitioning to the built-up area (and not in the retail zone; see Fig. 2). The pedestrian left a house on the left side of the road and was visible for the driver from a time to collision (TTC) of 4 s onwards, which equals the TTC used in a field experiment by Lubbe and Rosén (2014) focused on determining comfort boundaries for the intervention of a warning system for safe pedestrian crossings. The pedestrian moved at 1.2 m/s (Fitzpatrick, Brewer, & Turner, 2006) and was always wearing the same clothes (red sweater).

2.4. Procedure

All participants gave written informed consent, and were asked for a selection of demographic information. After adjusting their driving seat, participants received a short description of the simulator and the eye tracker. The exact purpose of the study was not revealed in advance.

Participants drove a 6.4 km practice session to get acquainted with the simulator. This was a new terrain (not one of the experimental scenarios) and had some common characteristics of the experimental scenarios (built-up areas, retail areas, etc.). However, there was no billboard present nor some crossing pedestrians. First, the driver received a straight stretch of road, and had to stop and accelerate a few times, followed by a few small and large curves. The eye-tracking equipment was calibrated with FaceLAB and EyeWorks™ software.

Participants completed seven scenarios in a randomized order to avoid order effects (Field, 2009). Before each scenario, participants were instructed to drive as they would normally do.

Participants completed the NASA Task Load Index (NASA-TLX) that is a subjective measure for workload (Hart & Staveland, 1988), and also commonly used within the field of driving psychology (e.g. Benedetto et al., 2011; Edquist et al., 2009). The index is multi-dimensional and can result in an overall workload score based on (a weighted average of) six subscales: mental demand, physical demand, temporal demand, own performance, effort and frustration (Hart & Staveland, 1988; Hart, 2006). Over the years, several authors have proposed modifications with most importantly elimination of the weighting process (RAW TLX), and separate analysis of the subscales instead of computation of an overall workload score (Hart, 2006). The index was fulfilled only after driving scenario 1 (scenario without a digital billboard) and scenario 2 (scenario with a digital billboard, display time 3 s and distance 41 m) because both scenarios were driven on the same terrain (see Fig. 2). By doing this, we exclude possible bias due to a difference in driving environment (curves, other traffic, etc.) and we measure the presence of a digital billboard (with a short display time and near the pedestrian crossing).

After the experiment, participants completed a short questionnaire and were debriefed.

2.5. Data collection and analysis

For all statistical analyses in IBM SPSS Version 23, the type I error (α) was set at 0.05. ANOVAs were corrected for deviations from sphericity (Greenhouse-Geisser epsilon correction). The corrected *F value*, probability values and degrees of freedom are reported as well as a measure of effect size. Comparisons marked with an asterisk were significant at the 0.05 significance level.

3. Results

3.1. Glance behavior

The average number of glances on the digital billboard and the total eye glance duration (i.e. the accumulated total time that the participants looked at a sign; Dukic, Ahlstrom, Patten, Kettwich, & Kircher (2012) calls this "dwell time") were analyzed in a repeated-measures ANOVA with 'display time' (3 s, 6 s and 15 s), 'prior distance from a pedestrian crossing' (41 m and 65 m) and 'road environment' (transition zone to a built-up area and retail zone) as factors.

3.1.1. Average number of glances on digital billboard

We found no main effect for 'distance' ($F(1, 28) = 3.39$, $p = .08$, $h_p^2 = 0.11$) while we did find one for 'display time' ($F(1.90, 53.29) = 43.12$, $p = .00$, $h_p^2 = 0.61$). We observed more glances in the retail zone compared to the transition zone to a built-up area ($F(1, 28) = 39.64$, $p = .00$, $h_p^2 = 0.59$).

In addition, we established a significant two-way interaction effect of 'distance' $\times$ 'display time' ($F(1.50, 42.12) = 12.31$, $p = .00$, $h_p^2 = 0.31$) indicating that, depending on the distance of the digital billboard, display time has a different effect on the average number of glances (Fig. 3 and Table 2). Fig. 3 indicates that a longer display time of the message on the digital billboard was associated with less eye glances on the digital billboard. In Fig. 3 the average number of glances was always

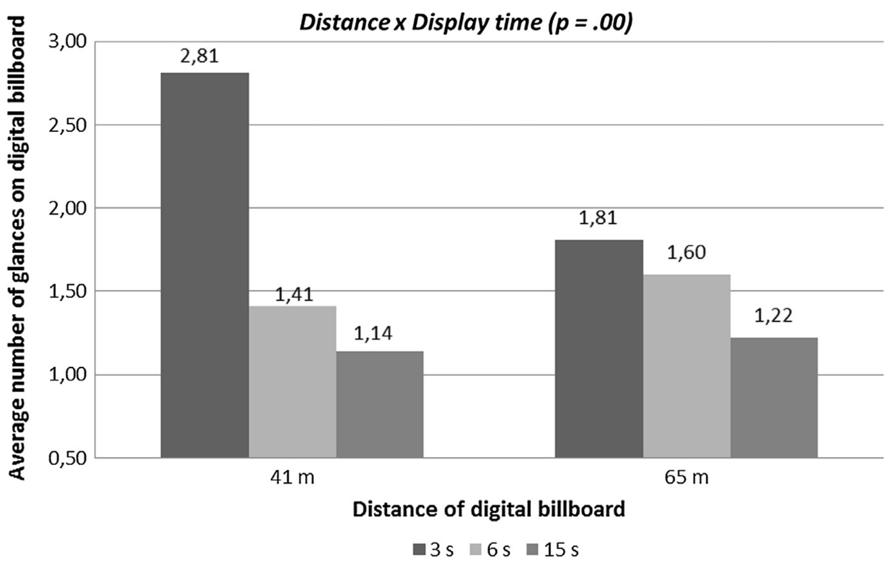

Fig. 3. Significant two-way interaction effect 'distance' × 'display time' for the average number of glances on the digital billboard.

Table 2
Significant two-way interaction effect 'distance' × 'display time' for the average number of glances on the digital billboard.

Effect	Display time	Distance	Display time	Distance	Paired samples *t*-test
Distance * Display time	3 s	41 m	3 s	65 m	***t*(28) = 3.38, *p* = .00, *r* = 0.60***
	6 s	41 m	6 s	65 m	*t(28) = −1.09, p = .29, r = 0.20*
	15 s	41 m	15 s	65 m	*t(28) = −0.54, p = .59, r = 0.10*
	3 s	41 m	6 s	41 m	***t(28) = 8.65, p = .00, r = 0.85****
	3 s	41 m	15 s	41 m	***t(28) = 7.67, p = .00, r = 0.82***
	6 s	41 m	15 s	41 m	*t(28) = 1.61, p = .12, r = 0.30*
	3 s	65 m	6 s	65 m	*t(28) = 1.04, p = .31, r = 0.20*
	3 s	65 m	15 s	65 m	***t(28) = 2.86, p = .01, r = 0.48****
	6 s	65 m	15 s	65 m	***t(28) = 3.08, p = .01, r = 0.50****

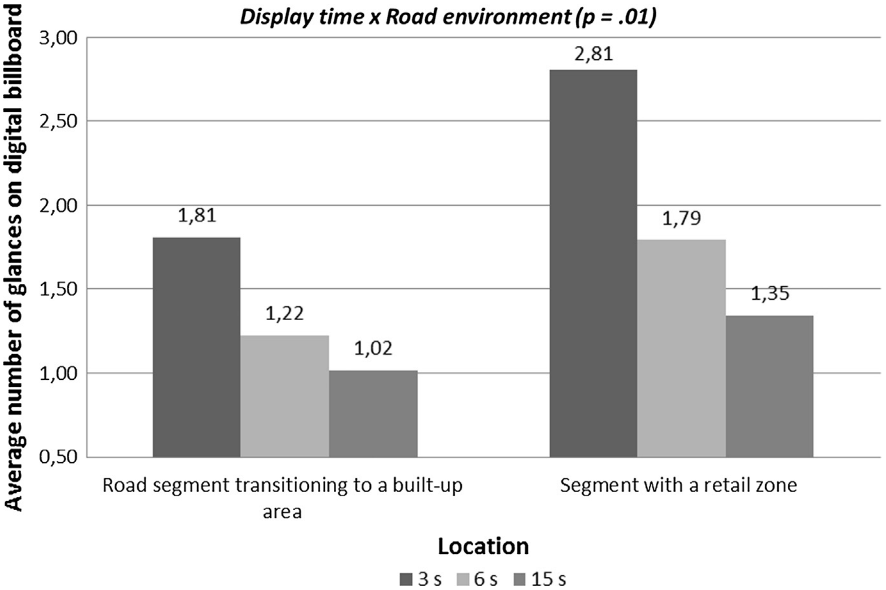

Fig. 4. Significant two-way interaction effect 'display time' × 'road environment' for the average number of glances on the digital billboard.

higher for a shorter display time, however, as can be seen in Table 2, the difference was not always significant. Separate tests for each display time demonstrated that a display time of 3 s induced significantly more glances towards the digital billboard at 41 m compared to 65 m. Separate tests for each distance indicated that at a distance of 41 m, significantly more glances went towards the digital billboard when it had a display time of 3 s compared to 6 s or 15 s. For a distance of 65 m, the difference between a display time of 3 s and 15 s and between 6 s and 15 s was significant.

Furthermore, we found a significant two-way interaction effect of 'display time' × 'road environment' ($F(1.49, 41.69) = 5.64$, $p = .01$, $h_p^2 = 0.17$). For each display time, we found significantly more glances in the retail zone compared to the transition zone to a built-up area. Fig. 4 shows that the average number of glances was always higher for a shorter display time. As can be seen in Table 3, only the difference between a display time of 6 s and 15 s, in the transition zone to a built-up area, was not significant.

Table 3
Significant two-way interaction effect 'display time' × 'road environment' for the average number of glances on the digital billboard.

Effect	Display time	Road environment	Display time	Road environment	Paired samples *t*-test
Distance * Road environment	3 s	Retail	3 s	Transition	***t*(28) = −5.38, *p* = .00, *r* = 0.71***
	6 s	Retail	6 s	Transition	***t*(28) = −4.14, *p* = .00, *r* = 0.62***
	15 s	Retail	15 s	Transition	***t*(28) = −2.44, *p* = .02, *r* = 0.42***
	3 s	Transition	6 s	Transition	***t*(28) = 3.69, *p* = .00, *r* = 0.57***
	3 s	Transition	15 s	Transition	***t*(28) = 4.54, *p* = .00, *r* = 0.65***
	6 s	Transition	15 s	Transition	*t*(28) = 1.40, *p* = .17, *r* = 0.26
	3 s	Retail	6 s	Retail	***t*(28) = 6.88, *p* = .00, *r* = 0.79***
	3 s	Retail	15 s	Retail	***t*(28) = 7.39, *p* = .00, *r* = 0.81***
	6 s	Retail	15 s	Retail	***t*(28) = 3.46, *p* = .00, *r* = 0.55***

Finally, neither the two-way interaction 'distance' × 'road environment' ($F(1, 28) = 2.81$, $p = .11$, $h_p^2 = 0.09$) nor the three-way interaction 'display time' × 'distance' × 'road environment' ($F(1.95, 54.61) = 1.68$, $p = .20$, $h_p^2 = 0.06$) was significant.

3.1.2. Total eye glance duration on digital billboard

There was no main effect of 'distance' ($F(1, 13) = 0.09$, $p = .77$, $h_p^2 = 0.01$), indicating that the total eye glance duration on a digital billboard at 41 m prior a pedestrian crossing ($M = 1.79$ s) was not different from 65 m ($M = 1.71$ s). The total eye glance duration for a display time of 3 s ($M = 1.84$ s) was not different compared to 6 s ($M = 1.82$ s) and 15 s ($M = 1.59$ s) because there was no main effect for display time ($F(1.98, 25.68) = 0.69$, $p = .51$, $h_p^2 = 0.05$). We found no main effect for 'road environment' (transition zone to a built-up area: $M = 1.57$ s; retail zone: $M = 1.92$ s; $F(1, 13) = 1.99$, $p = .18$, $h_p^2 = 0.13$). Furthermore, none of the two-way ('distance' × 'display time': $F(1.11, 14.44) = 0.19$, $p = .70$, $h_p^2 = 0.01$; 'distance' × 'road environment': $F(1, 13) = 1.78$, $p = .21$, $h_p^2 = 0.12$; 'display time' × 'road environment': $F(1.72, 22.38) = 3.22$, $p = .07$, $h_p^2 = 0.20$) or three-way interactions ('display time' × 'distance' × 'road environment': $F(1.93, 25.03) = 1.91$, $p = .17$, $h_p^2 = 0.13$) were significant.

3.1.3. Conclusion

Display time influenced the average number of glances on the digital billboard with a shorter display time resulting in more glances. However, the total eye glance duration was not influenced by display time. Furthermore, a road environment with retail stores generated more glances towards a digital billboard.

3.2. Workload

A paired samples *t*-test was conducted to compare scenario 1 (scenario without a digital billboard) and scenario 2 (scenario with a digital billboard, display time 3 s and distance 41 m).

Participants rated their experienced mental demand significantly higher when a digital billboard was present while they rated their own performance lower (Table 4). The ratings for the other four subscales were not significantly different.

3.3. Driving behavior

3.3.1. Average speed

Fig. 5 visualizes the average speed upstream and downstream from the location where drivers would stop reading the digital billboard (34 m prior to digital billboard). Speed-related behavior was more or less the same across the different scenarios. However, in scenarios with a display time of 3 s, the minimum approaching speed towards the crossing pedestrian was somewhat higher and was reached closer to the crossing than when there was no digital billboard or when the display time was longer. The approaching speed in presence of digital billboard with a display time of 3 s was 4–5 km/h or 23–27% higher than when no billboard was present (Table 5).

3.3.2. Standard deviation of lateral position

To test vehicle swerving in presence of a digital billboard, the standard deviation of lateral position (SDLP) in a zone of 150 m prior to the location where participants stopped reading the message was compared between the scenarios. Here the distance of the digital billboard from a pedestrian crossing was kept similar. Because we were not interested in an effect of road environment and to keep the effect of the digital billboard as pure as possible (i.e. no interference of a crossing pedestrian in the segment transitioning to a built-up area) we only did two repeated-measures ANOVA's in the segment with a retail zone. One ANOVA was done for the scenarios with a digital billboard at 41 m of the pedestrian crossing (four levels: scenario 1 (no billboard), scenario 2, scenario 4, scenario 6) and one at 65 m (four levels: scenario 1 (no billboard), scenario 3, scenario 5, scenario 7). The digital billboard was not present in scenario 1 but the same longitudinal zone of 150 m prior to the location where participants stopped reading the message of the billboard at 41 m or 65 m was used in the analysis.

Table 4
Paired samples *t*-test of workload.

Pair	Scenario	Mean	SE	Paired samples *t*-test
Mental demand	No digital billboard (Sc1)	6.80	0.85	**$t(34) = -2.87$, $p = .01$, $r = 0.44^*$**
	Digital billboard (Sc2)	8.63	0.72	
Physical demand	No digital billboard (Sc1)	5.94	0.82	$t(34) = 0.51$, $p = .61$, $r = 0.09$
	Digital billboard (Sc2)	5.57	0.65	
Temporal demand	No digital billboard (Sc1)	5.94	0.73	$t(34) = 0.33$, $p = .74$, $r = 0.06$
	Digital billboard (Sc2)	5.74	0.67	
Own performance	No digital billboard (Sc1)	13.48	0.68	**$t(34) = 2.49$, $p = 0.02$, $r = 0.40^*$**
	Digital billboard (Sc2)	11.51	0.90	
Effort	No digital billboard (Sc1)	7.37	0.89	$t(34) = -0.50$, $p = .62$, $r = 0.09$
	Digital billboard (Sc2)	7.65	0.82	
Frustration	No digital billboard (Sc1)	6.62	0.76	$t(34) = -1.72$, $p = .09$, $r = 0.28$
	Digital billboard (Sc2)	7.77	0.83	

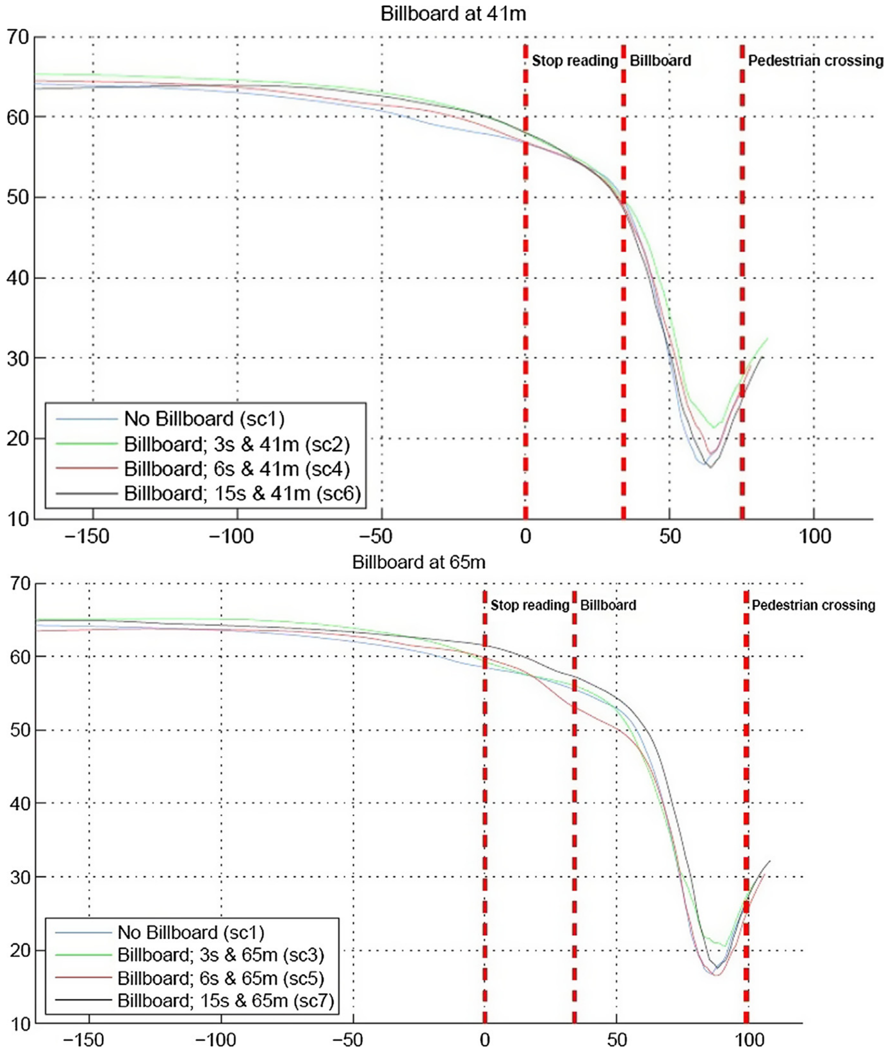

Fig. 5. Speed profile (km/h) towards the crossing pedestrian.

Table 5
Minimal approaching speed (km/h) towards crossing pedestrian.

	Digital billboard at 41 m			Digital billboard at 65 m		
	Speed (km/h)	Difference no billboard		Speed (km/h)	Difference no billboard	
	Minimum	Absolute	Percentage	Minimum	Absolute	Percentage
No Billboard	16.70	0	0%	16.70	0	0%
Display time 3 s	21.28	+4.58	+27%	20.55	+3.85	+23%
Display time 6 s	18.05	+1.35	+8%	16.51	−0.19	−1%
Display time 15 s	16.32	−0.38	−2%	17.50	+0.80	+5%

Although in every situation in the retail store environment the SDLP in the studied zone was lower in nonexistence of digital billboard, the repeated-measures ANOVA revealed that the difference was not significant (billboard at 41 m: $F(1.95, 66.32) = 0.42$, $p = .65$, $h_p^2 = 0.01$; billboard at 65 m: $F(2.91, 98.78) = 0.34$, $p = .79$, $h_p^2 = 0.01$).

3.3.3. Behavior towards the crossing pedestrian

Because drivers' expectancy can impact reaction times (Ruscio, Ciceri, & Biassoni, 2015), only the first encounter for each participant was considered. Therefore, we limit ourselves to descriptive statistics for Brake Reaction Time (BRT) and number of (complete) stops.

Table 6
Stopping behavior and BRT towards crossing pedestrian in transition zone to a built-up area.

	Display time	Distance	BRT	Total # as 1st trip	Stopped for pedestrian		Not stopped for pedestrian	
					#	%	#	%
Scenario 1	No digital billboard		1.09	4	3	75%	1	25%
Scenario 2	3 s	41 m	1.55	9	4	44%	5	56%
Scenario 3	3 s	65 m	1.36	2	2	100%	0	0%
Scenario 4	3 s	41 m	1.48	4	4	100%	0	0%
Scenario 5	6 s	65 m	1.56	5	5	100%	0	0%
Scenario 6	6 s	41 m	1.45	7	7	100%	0	0%
Scenario 7	6 s	65 m	1.62	4	4	100%	0	0%

The BRT towards a crossing pedestrian in the transition zone to a built-up area was approximately 1.5 times higher when a digital billboard was present (Table 6). There was no difference in the scenarios with a digital billboard (i.e., there was no effect of 'display time' and 'distance').

The majority (56%) did not come to a complete stop for a crossing pedestrian in case of a digital billboard at 41 m with a display time of 3 s (Table 6). There was also one person who did not stop for the pedestrian when no digital billboard was present.

4. Discussion & conclusion

4.1. Glance behavior

Short display times of the billboard message (i.e. high switching frequency) resulted in more eye glances than longer display times. This is in line with the findings of Chattington et al. (2009) and can be explained by the fact that people are curious when a message changes, which stimulates looking again (Molino, Wachtel, Farbry, Hermosillo, & Granda, 2009). This is related to the principle of attention conspicuity (object conspicuity) that is defined by Cole and Hughes (1984) as the capacity of an object to attract attention when it is unexpected. We also found more glances in the segment with a retail zone than in the road segment transitioning to a built-up area. This could be explained, on the one hand, by the fact that drivers might expect advertising in this kind of area. On the other hand, it is related to the principle of search conspicuity that refers to the ability of an object to be found if the driver is really looking for it (Cole & Hughes, 1984). There were no important differences between a billboard at 41 m or 65 m prior to the pedestrian crossing. However, the highest number of glances was reached with a display time of 3 s for a billboard located 41 m prior to the pedestrian crossing. Thus a short display time together with a short distance between the billboard and the pedestrian crossing resulted in the most negative glance behavior. Therefore, from a safety perspective, it would be beneficial if drivers would restrict the number of glances on a digital billboard that is close to a pedestrian crossing. Thus, it is recommended not to place billboards in the direct vicinity of pedestrian crossings.

The total eye glance duration on the billboard was never more than 2 s. Klauer, Dingus, Neale, Sudweeks, and Ramsey (2006) indicates that glance behavior with a total eyes-off-road duration of more than 2 s significantly increases individual near-crash or crash risk whereas glance durations less than 2 s did not significantly increase risk relative to normal driving. However, Borowsky et al. (2016) argue that even short visual interruptions will have a negative impact on drivers' ability to anticipate a potential hazard. Poor hazard perception has been associated with increased crash risk (Horswill, Hill, & Wetton, 2015). Thus, even short eye fixations on a digital billboard could jeopardize drivers' safety. This is because paying no attention to the road might imply missing critical on-road information with slower and less accurate reactions as a consequence (Holahan, Culler, & Wilcox, 1978). Although we did not formally analyze this, there seems to be some indication to support this hypothesis, given that brake reaction times were almost 1.5 times higher when a digital billboard was present.

4.2. Workload

Compared to the scenario with a digital billboard (i.e. scenario 2), the scenario without a digital billboard (i.e. scenario 1) was rated "better" for every subscale of the RAW TLX. However, the difference was only significant for mental demand and own performance subscales.

4.3. Driving behavior

A quick reaction when facing a critical situation can make the difference between avoiding a collision or colliding with another road user, for example a pedestrian. The brake reaction time towards the crossing pedestrian was approximately 1.5 times higher when a digital billboard was present, regardless of the display time (this was not tested statistically). Milloy and Caird (2011) also found that participants took significantly longer to respond to a braking lead vehicle when they passed video billboards than when they passed traditional static billboards or did not pass a billboard at all. Although we did not formally analyze this (no statistical test), the results of our study confirm that the presence of a digital billboard, regardless of the characteristics of the billboard, has an important effect on the brake reaction time. Furthermore, the lowest approaching speed towards the crossing pedestrian was systematically (somewhat) higher and reached closer to the pedestrian when a digital billboard was present, with a display time of 3 s coming out as the most dangerous condition. The crash severity would therefore be highest in this condition. Indeed, higher speed generates a more severe collision impact, which increases the consequences in terms of injury and material damage (Elvik, Vaa, Erke, & Sorensen, 2009). We also observed that participants (Table 6) more frequently did not reach a full stop for a crossing pedestrian in case of a digital billboard at 41 m and a display time of 3 s (they hit the pedestrian or made an evasive steering maneuver). A possible explanation for this was the poor brake reaction time in the presence of a digital billboard and the fact that there were more eye glances towards the digital billboard when the display time of the message was short, resulting in late pedestrian recognition. Other research also shows that when driving with peripheral vision, a braking lead car is noticed later (Summala, Lamble, & Laakso, 1998). We observed no significant difference in the standard deviation of lateral position when digital billboard was present or not. Related to this finding, Summala, Nieminen, and Punto (1996) showed that drivers are still able to keep track when driving with eyes off the road.

4.4. Conclusion

Although not all outcomes on surrogate traffic safety measures reached statistical significance, this study provides several indications that digital billboards have a negative impact on workload, glance behavior, driving behavior and, consequently, on traffic safety. It appears that a display time of 3 s has the most negative effect. The following practical recommendations can be given:

- Avoid too short display times (i.e., the longer the better);
- Avoid installation of digital billboards signs in the vicinity of already attention demanding locations.
- Traffic safety will increase not only by enlarging the display time but also, simultaneously, by increasing the distance between the billboard sign and the attention demanding location.

5. Limitations and future research

A driving simulator has various advantages over real-vehicle observations (De Winter, Van Leeuwen, & Happee, 2012; Matas, Nettelbeck, & Burns, 2015). Data collection is easy and accurate and the carefully controlled production of driving scenarios without exposing the participant to any (life threatening) risk are among its advantages. However, the display system in terms of image resolution, color accuracy and luminance range is a limitation of all driving simulators (Fuller, 2004). However, since we were interested in relative differences between the seven tested conditions, this study provides reliable results (i.e. the direction or relative magnitude of the effect is similar to reality).

The content of the different messages was more or less the same (a commercial picture) and changed randomly. We have not tested formally if the pictures were sufficiently dissimilar, but the results (i.e. more eye glances when there was a higher switching frequency and thus another message/picture) showed an effect of a changing message.

Limited sample size prevented the set up of a fully counterbalanced design (order of scenario presentation). Furthermore, we limited ourselves for some analyses to only implement the first trip a participant encountered an event (we don't want to have learning or order effects). Therefore, it was not possible to always perform a statistical analysis. Due to calibration issues, eye tracking data was not available for all participants.

We did not analyze a direct relation between digital billboards and collisions, but used different surrogate safety measures. A before-and-after study with the same characteristics as used in this study could further reveal a direct relationship.

This study only focused on the display time of the message and the location of the billboard. However, there are also other functional characteristics and placement conditions that have an impact. Therefore, further studies should elaborate this study and develop a comprehensive model with various features and characteristics, which can predict the optimal location and other characteristics of a billboard.

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