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The effect of billboard design specifications on driving: A driving simulator study

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ABSTRACT

Research on the effect of advertising billboards on road safety has accumulated over the past seven decades, but has led to inconclusive data, which prevent clear-cut conclusions. To enhance road safety, it was suggested that researchers should shift their efforts to exploring which billboard characteristics are distracting by nature. This line of research may promote the establishment of concrete guidelines for the least distracting permissible billboards. A previous study classified billboards into three clusters: 1. Loaded (colorful billboards with small quantities of graphic elements and large quantities of text); 2. Graphical (colorful billboards with large quantities of graphic elements and small quantities of text); and 3. Minimal (billboards with few or no graphic elements, few colors, and a small amount of text). The current study systematically explores the effect of these three clusters on drivers' performance in a driving simulator. Eighteen participants drove in scenarios which systematically manipulated the following variables: the perceptual load on the road, the perceptual load on the sides of the road, location of preplanned critical events, and the presence of billboards from each one of the three previously identified clusters. The findings show that the presence of billboards from the Loaded and Minimal clusters significantly compromised road safety in various experimental conditions. However, the presence of billboards from the Graphical cluster significantly affected drivers' performance only in one experimental condition. The conclusion, for the time being, is that Graphical billboards, which include a large quantity of graphic elements with few or no textual elements, are the least harmful while driving.

1. Introduction

Over the last seven decades many studies have been conducted in order to estimate the influence of advertising billboards on various road safety related variables. For example, researchers have explored the effect of billboards on ***accident rates***. While some studies showed correlation between the presence of billboards and higher accident rates (e.g., Ady, 1967; Holohan et al., 1978; Rusch, 1951; Staffeld, 1953), more recent studies did not find evidence for such correlation (e.g., Izadpanah et al., 2014; Smiley et al., 2005; Yannis et al., 2013). Other studies focused on ***vehicle speed***, showing decreased mean speed when driving at settings with more advertising billboards (e.g., Edquist and Johnston, 2008; Horberry et al., 2006; Pavlou et al., 2018). Yet, there are also findings of non-effect, minor effect, or insignificant effect of billboards on vehicle speed (e.g., Bendak and Al-Saleh, 2010; Lee et al., 2007, 2003). Marciano and Yeshurun (2012) distinguished the effect of overall visual load from the effect of the presence of billboards on drivers speed and found that while the former decreased driver speed, the latter increased it. Another investigated driving performance measurement that also yielded conflicting results is ***lane-keeping***. Lee et al. (2003) did not find any effect of billboards' presence on lane-keeping performance, but other researchers reported a deterioration in performance (e.g., Bendak and Al-Saleh, 2010; Lee et al., 2007; Pavlou et al., 2018; Young et al., 2009). Some researchers used driving simulator studies and showed ***longer reaction times*** to critical events in the presence of billboards (e.g., Marciano and Yeshurun, 2012; Pavlou et al., 2018). Finally, the influence of advertising billboards was also explored via ***eye movements data*** (as measurement of visual attention drawn by the billboards). For example, Herrstedt et al. (2013) reported relatively high percent of long glances, lasting a second or more, at a billboard, while Misokefalou et al. (2016) reported a bit shorter glance duration, of 0.86 s. Dukic et al. (2013) found longer dwell times for dynamic billboards in comparison with traffic signs. In contrast, other researchers found much shorter glance durations, e.g., Costa et al. (2019) who reported 0.3 s glance duration, and Samsa (2015) who found even shorter ones (0.2 s). Accordingly, Decker et al. (2015) claimed that these short glance durations do not consider to be a distraction of the driver to a dangerous degree, because the driver can regulate the attention allocated to the billboards when the driving demands increases. Some researchers focused on the drivers' or on the billboards' variables,

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in their attempt to explain the effect of billboards on glance durations. For example, Edquist et al. (2011), as well as Stavrinos et al. (2016), showed that the influence of advertising billboards on visual scanning was modulated by the driver age; Targosiński (2017) found that the eye movements data of various drivers are affected differently depending on the billboards' content and on the specific driver's sensitivity to the particular content; and Tarnowski et al. (2017) claimed that dwell time was influenced by the density of the billboards.

A recent literature review came to the conclusion that the current accumulated data on this topic does not make it possible to deduce a clear and direct relationship between the presence of advertising billboards and road collisions, because the majority of the relevant findings are inconclusive (Oviedo-Trespalacios et al., 2019). A similar yet more generalized conclusion, was derived for the other variables mentioned above (Marciano and Setter, 2017; Vlakveld and Helman, 2018). The ambiguity of different findings that have been published over the last seven decades might stem from the fact that various studies looked at different types of billboards, different populations of drivers, and explored the question under different driving conditions.

The indecisive status of this important question may reflect an appropriate degree of caution among researchers, who are unwilling to draw clear-cut conclusions based on inconclusive data. Nevertheless, this indecisive position also prevents deriving straightforward recommendations for banning or restricting the presence of billboards, and at the same time it well serves the financial interests of the powerful advertising industry. Given this situation, it can be assumed that advertising billboards will maintain a presence on all types of roads around the globe. In light of this assumption, it would be beneficial for researchers in the field of road safety to shift their research efforts from the mere question of the effect of the presence of billboards on various road safety factors to research that focuses on identifying the most (and least) distracting billboard characteristics. The aim of this line of research should be to develop concrete guidelines for permissible billboards. Such guidelines may ensure that those billboards allowed will be the least distracting as possible.

Recently, Marciano and Setter (2017) published an article that attempted to take a first step in this direction. Using a psychophysical experiment, they explored the effect of various characteristics of actual static billboards (e.g., percentage of text versus graphics, text size, and the number of colors, logos, and information items) on the performance of two driving-related basic tasks (tracking task and color-change identification task). The findings of Marciano and Setter (2017) point to three clusters of billboards that affected these two tasks differently, as detailed below. ***1. Loaded Billboards*** mostly led to a deterioration in performance on the tracking task, designed to mimic lane keeping while driving. These billboards were colorful, comprised of proportionately small quantities of graphic elements and large quantities of text, which consisted of many letters of all sizes, and also included many logos and many information items (e.g., telephone numbers, dates, address, etc.). ***2. Graphical Billboards*** mostly led to a drop in performance on the color-change identification task, designed to mimic attention to changing traffic lights while driving. These billboards were colorful, and contained large quantities of graphic elements and small quantities of text. ***3. Minimal Billboards*** had the least effect on the performance of both tasks within the psychophysical study. These billboards were characterized as having few or no graphic elements, few colors, and a small amount of text with mainly large letters.

Marciano and Setter (2017) stressed that no direct implications should be derived from the results of their psychophysiological experiment for the purpose of the driving task. The task of driving is much more complex than the controlled multi-task experiment in the psychophysical study. Therefore, the main purpose of the current study was to test the influence of these three billboard clusters on driving performance and on the probability of collision, in a real driving setting within a driving simulator. For example, one important variable that could not be assessed at all in the previous psychophysical experiment, was responses to unexpected critical events. Indeed, a previous study found that in some cases billboard presence interferes with drivers' responses to such events (Marciano and Yeshurun, 2012).

The current study employed an up to date experimental paradigm (see Marciano and Yeshurun, 2015), which is based on the concept of "perceptual load". In the domain of cognitive psychology, the term perceptual load was suggested as a factor that mediates the ability (or sometimes inability) of people to selectively allocate their attention (for more details about the perceptual load concept see Lavie, 1995; Lavie and Cox, 1997; Marciano and Yeshurun, 2011). This novel driving simulator paradigm takes into account three important factors: (a) perceptual load on central regions of the visual field (low versus high), i.e., the perceptual load on the road, (b) perceptual load on peripheral regions of the visual field (low versus high), i.e., the perceptual load on the sides of the road; and (c) the location in which a preplanned critical event took place: events that occurred on the road versus events that were initiated from the sides of the road. To assess the influence of each of the previously classified three clusters of billboards on real driving performance (e.g., accident's rate and reaction to critical preplanned events), the current study also explored the effect of billboards classified as belonging to one of these three clusters: Minimal, Graphical, or Loaded (Marciano and Setter, 2017). If the findings of the former psychophysical experiment (Marciano and Setter, 2017) are applicable to more real driving conditions, then it is assumed that all the driving performance measurements would be affected the least by billboards from the Minimal cluster, and would be affected the most by billboards from the Loaded cluster. Otherwise, a different pattern of influence of the various clusters of billboards on the driving performance measurements may emerge.

2. Material and method

2.1. Participants

Eighteen participants (9 women), all students at the University of Haifa, took part in the experiment in return for a monetary reward. The average age of the participants was 27.2 years (ranging from 22 to 40). All of them had driving experience of at least five years. The study was approved by the Ethics Committee of the University of Haifa and each participant signed an informed consent form.

2.2. Tools and procedure

The study took place in a partial driving simulator using STISIM Drive® software on a PC computer. A Logitech steering system, which included a steering wheel and gas and brake pedals, was used. The participant sat on a stationary office chair, 2.5 m in front of a wide screen (2.3 × 3 m) subtending 62° of visual angle. A speaker providing background sounds was placed behind the participant.

2.3. Driving scenarios

2.3.1. General

Six different 28-km-long scenarios simulated a suburban road with two lanes in each direction, separated by a road median. Each scenario consisted of four load conditions, with balanced order between the scenarios, involving different combinations of central (the road) and peripheral (the sides of the road) perceptual load levels: **a.** Low levels of load in both areas (LL, see Table 1), **b.** High levels of load on the road with low levels of load on its sides (HL, see Table 1), **c.** Low levels of load on the road with high levels of load on its sides (LH, see Table 1), and **d.** High levels of load in both areas (HH, see Table 1; for more details about this paradigm see Marciano and Yeshurun, 2015).

Central (road) load was manipulated via the number and congestion of vehicles on the road (high perceptual load: approximately 40 vehicles per kilometer in each direction; low perceptual load:

Table 1
Description of the experimental scenarios – perceptual load conditions and critical events' description.

Scenario Number	Perceptual load level on the road and its sides		Events on the road			Events initiated from the sides		
			1	2	3	1	2	3
A	0–7.5 km	LH	Motorcycle brakes	Bicycle brakes	Car brakes	Pedestrian crosses	Parked car enters the road	Car backs up
	7.5–14 km	LL	Bicycle brakes	Car brakes	Motorcycle brakes	Car backs up	Parked car enters the road	Dog crosses
	14–21.5 km	HL	Car brakes	Car brakes	Car brakes	Parked car enters the road	Car backs up	Pedestrian crosses
	21.5–28 km	HH	Car brakes	Car brakes	Car brakes	Car backs up	Pedestrian crosses	Parked car enters the road
B	0–7.5 km	HL	Car brakes	Car brakes	Car brakes	Pedestrian crosses	Parked car enters the road	Car backs up
	7.5–14 km	LH	Bicycle brakes	Car brakes	Car brakes	Car backs up	Parked car enters the road	Pedestrian crosses
	14–21.5 km	HH	Car brakes	Motorcycle brakes	Car brakes	Parked car enters the road	Pedestrian crosses	Car backs up
	21.5–28 km	LL	Bicycle brakes	Car brakes	Car brakes	Parked car enters the road	Car backs up	Pedestrian crosses
C	0–7.5 km	LL	Bicycle brakes	Car brakes	Car brakes	Car backs up	Parked car enters the road	Pedestrian crosses
	7.5–14 km	HL	Car brakes	Motorcycle brakes	Car brakes	Parked car enters the road	Car backs up	Pedestrian crosses
	14–21.5 km	LH	Motorcycle brakes	Car brakes	Car brakes	Pedestrian crosses	Parked car enters the road	Car backs up
	21.5–28 km	HH	Car brakes	Car brakes	Car brakes	Pedestrian crosses	Pedestrian crosses	Parked car enters the road
D	0–7.5 km	HH	Car brakes	Car brakes	Car brakes	Pedestrian crosses	Parked car enters the road	Car backs up
	7.5–14 km	LH	Motorcycle brakes	Car brakes	Car brakes	Car backs up	Pedestrian crosses	Parked car enters the road
	14–21.5 km	LL	Car brakes	Motorcycle brakes	Bicycle brakes	Parked car enters the road	Car backs up	Pedestrian crosses
	21.5–28 km	HL	Car brakes	Car brakes	Car brakes	Pedestrian crosses	Parked car enters the road	Car backs up
E	0–7.5 km	LH	Motorcycle brakes	Car brakes	Car brakes	Parked car enters the road	Pedestrian crosses	Parked car enters the road
	7.5–14 km	HL	Car brakes	Car brakes	Car brakes	Car backs up	Pedestrian crosses	Parked car enters the road
	14–21.5 km	HH	Car brakes	Car brakes	Car brakes	Car backs up	Pedestrian crosses	Parked car enters the road
	21.5–28 km	LL	Car brakes	Motorcycle brakes	Bicycle brakes	Pedestrian crosses	Car backs up	Parked car enters the road
F	0–7.5 km	LL	Car brakes	Car brakes	Car brakes	Parked car enters the road	Pedestrian crosses	Car backs up
	7.5–14 km	HH	Car brakes	Car brakes	Car brakes	Car backs up	Pedestrian crosses	Parked car enters the road
	14–21.5 km	LL	Bicycle brakes	Motorcycle brakes	Car brakes	Parked car enters the road	Pedestrian crosses	Car backs up
	21.5–28 km	HL	Car brakes	Car brakes	Car brakes	Car backs up	Parked car enters the road	Pedestrian crosses

LL – low levels of load on both regions; LH: low levels of load on the road with high levels of load on the sides of the road; HL: high levels of load on the road with low levels of load on the sides of the road; HH: high levels of load on both regions.

approximately 6 vehicles per kilometer in each direction). Peripheral load (sides of the road) was manipulated via the number and spacing of standing and moving pedestrians, buildings, and parked vehicles (high perceptual load: approximately 160 pedestrians, 45 buildings, and 20 parked vehicles per kilometer, in each direction; low perceptual load: approximately 4 pedestrians, 8 buildings, and 4 parked vehicles per kilometer, in each direction).

2.3.2. Critical events

Each scenario included 24 preplanned critical events, twelve on the road (e.g., a leading car suddenly slowed down) and twelve that were initiated from the sides of the road (e.g., a pedestrian crossed the road unexpectedly, see Table 1 for more details). All events were designed to lead to a collision unless corrective action is taken. Events were balanced within each of the four perceptual load conditions; in each condition of each scenario three events occurred on the road and three events were initiated from the sides of the road, for a total of six events in each load condition of each scenario (Table 1).

2.3.3. Advertising billboards

All the billboards in the study were real static billboards photographed on the streets of Israel, that had been used in a previous psychophysical experiment in which three clusters of billboards - Loaded, Graphical, and Minimal - were identified (Marciano and Setter, 2017). To prevent a situation in which a participant would be exposed to the same billboard twice within one experimental session, two sets of nine different billboards from each cluster (termed Set A and Set B, 18 different billboards from each cluster, for a total of 72) were chosen to be presented near each of the preplanned critical events or near a curve. An example of each of these three clusters (written in Hebrew) can be seen in Fig. 1. In addition, 16 other billboards derived from the pool of the previous psychophysical experiment, which were not classified as belonging to any of the above three clusters, were placed in locations where no critical preplanned event occurred. The purpose of these additional billboards was to prevent a one-on-one association between the presence of a billboard and the occurrence of a critical event. Finally, to enable exploring the effect of the billboard clusters on lane keeping, three curves were simulated in each scenario, but only in the segment of low load in both regions of the visual field. This specific condition was chosen to allow relatively high driving speed and at the same time ensure that the driver would be able to perceive the billboard. A billboard, one from each cluster, was placed near the end of each curve in scenarios that included billboards (see Table 2).

2.3.4. Versions of scenarios

Three different versions of each of the six scenarios were created. First, as a ***baseline*** scenario, no billboards were placed near the critical events. The baseline scenario version included only 16 billboards (four in each combination of central and peripheral perceptual load conditions, see Table 2, which were not classified as belonging to any of the above three clusters) that were located at sporadic locations throughout the driving track and were always far from the preplanned critical events.

Next, two versions of ***with billboard*** scenarios were created, to be compared with the equivalent baseline scenario. These scenarios included 43 different billboards: 24 billboards derived from the three clusters of billboards in Set A, for one version of these scenarios, or in Set B for the other, were placed near preplanned critical events (12 near events that occurred on the road and the other 12 near events that were initiated from the sides, see Table 2). In addition, three more billboards, one of each cluster (from Set A or B, respectively) were placed near a curve (Table 2). Finally, additional 16 other billboards were located at non-event sporadic locations throughout the scenarios (Table 2).

The 24 billboards that were located near a preplanned critical event were placed with the following balance: In each load condition two billboards from each cluster (Loaded, Graphical, and Minimal) were presented, one near an event that occurred on the road (see details in Table 2 and examples in Fig. 2a–c) and the other near an event that was initiated from its sides (see details in Table 2 and examples in Fig. 2d, e, and f). The billboards near the side events were always located on the contralateral side of the event. For events initiated from the right sidewalk, the billboard was located on the road median (Fig. 2d and f) and vice versa (Fig. 2e). The aim of this balance was to prevent a situation in which capturing the attention of the driver by the billboard may facilitate the detection of a critical event occurring nearby, concealing the effect of the billboard.

2.4. Procedure

Each participant took part in four experimental sessions. In the first session, after signing an informed consent form, the experimenter presented the experimental instructions. To conceal the interest in the billboards, the participants were told that the experiment “tests driving habits in different visibility conditions” and that “you belong to an experimental group which drives in good visibility condition”. The participants were then asked to sit in an office chair, hold a steering wheel, that was attached to a desk, and put their right foot next to the gas and brake pedals, which were placed on the floor. They were told

Fig. 1. Examples of (a) Loaded billboards, (b) Graphical billboards, and (c) Minimal billboards.

Table 2
Description of the experimental scenarios – Billboards' clusters.

Scenario Number	Perceptual load level on the road and its sides		Number of Non-clustered billboards	Events on the road			Events initiated from the sides			Curves		
				1	2	3	1	2	3	1	2	3
A	0–7.5 km	LH	4	Minimal	Graphical	Loaded	Graphical	Minimal	Loaded			
	7.5–14 km	LL	4	Graphical	Minimal	Loaded	Minimal	Loaded	Graphical	Loaded	Minimal	Graphical
	14–21.5 km	HL	4	Minimal	Graphical	Loaded	Graphical	Loaded	Minimal			
	21.5–28 km	HH	4	Minimal	Loaded	Graphical	Minimal	Graphical	Loaded			
B	0–7.5 km	HL	4	Minimal	Graphical	Loaded	Loaded	Graphical	Minimal			
	7.5–14 km	LH	4	Minimal	Graphical	Loaded	Loaded	Graphical	Minimal			
	14–21.5 km	HH	4	Minimal	Loaded	Graphical	Loaded	Graphical	Minimal			
	21.5–28 km	LL	4	Loaded	Graphical	Minimal	Minimal	Loaded	Graphical	Minimal	Graphical	Loaded
C	0–7.5 km	LL	4	Loaded	Minimal	Graphical	Loaded	Minimal	Graphical	Minimal	Graphical	Loaded
	7.5–14 km	HL	4	Loaded	Minimal	Graphical	Minimal	Loaded	Graphical			
	14–21.5 km	LH	4	Loaded	Minimal	Graphical	Minimal	Graphical	Loaded			
	21.5–28 km	HH	4	Minimal	Graphical	Loaded	Minimal	Loaded	Graphical			
D	0–7.5 km	HH	4	Loaded	Minimal	Graphical	Minimal	Graphical	Loaded			
	7.5–14 km	LH	4	Minimal	Graphical	Loaded	Loaded	Graphical	Minimal			
	14–21.5 km	LL	4	Minimal	Graphical	Loaded	Loaded	Minimal	Graphical	Loaded	Graphical	Minimal
	21.5–28 km	HL	4	Minimal	Graphical	Loaded	Loaded	Minimal	Graphical			
E	0–7.5 km	LH	4	Minimal	Graphical	Loaded	Minimal	Graphical	Loaded			
	7.5–14 km	HL	4	Loaded	Graphical	Minimal	Loaded	Minimal	Graphical			
	14–21.5 km	HH	4	Loaded	Minimal	Graphical	Loaded	Minimal	Graphical			
	21.5–28 km	LL	4	Minimal	Graphical	Loaded	Minimal	Loaded	Graphical	Loaded	Minimal	Graphical
F	0-7.5 km	LL	4	Loaded	Minimal	Graphical	Loaded	Minimal	Graphical			
	7.5–14 km	HH	4	Loaded	Minimal	Graphical	Loaded	Minimal	Graphical			
	14–21.5 km	LL	4	Loaded	Minimal	Graphical	Minimal	Loaded	Graphical	Minimal	Graphical	Loaded
	21.5–28 km	HL	4	Loaded	Graphical	Minimal	Loaded	Minimal	Graphical			

LL – low levels of load on both regions; LH: low levels of load on the road with high levels of load on the sides of the road; HL: high levels of load on the road with low levels of load on the sides of the road; HH: high levels of load on both regions.

that the dynamic driving scenario would be presented on a wide screen in front of them and that their task is to drive until the end of the road. They were asked to comply with all traffic laws (e.g., traffic signs, traffic signals, speed limits, etc.). The participants drove in a practice scenario that took about half an hour, in order to get used to the simulator. In each of the other three experimental sessions, about an hour each, the participant drove in two experimental scenarios. In one of these three experimental sessions the baseline scenarios that did not include billboards near the preplanned critical events were used (as control condition), while the scenarios in the other two sessions included billboards (from Set A in one of these sessions and from Set B in the other experimental condition). To prevent fatigue or practice effects, the order of the three experimental sessions, as well as the order of the scenarios within each session, was balanced across participants.

To sum, each participant drove in six different 28 km long scenarios. Two of these scenarios included only 16 billboards, which were not classified as any of the billboard clusters (non-clustered billboards, see Table 2), and were not located near a preplanned event. These scenarios can be viewed as the control condition to be compared with the experimental condition, which consisted of the other four scenarios that contain billboards from the three clusters (Loaded, Minimal, and Graphical). Each one of these four scenarios included, in addition to 16

Fig. 2. Examples of billboards and critical events (a) Billboard from the Loaded cluster located near an event on the road (motorcycle that suddenly brakes in front of the driver); (b) Billboard from the Graphical cluster located near an event on the road (the red leading vehicle moves from the right to the left and brakes in front of the driver); (c) Billboard from the Minimal cluster located near an event on the road (a vehicle brakes in front of the driver); (d) Billboard from the Loaded cluster located near an event initiated from the sides of the road (a pedestrian crosses the road from right to left); (e) Billboard from the Graphical cluster located near an event initiated from the sides of the road (a pedestrian crosses the road from the road median to the right); and (f) Billboard from the Minimal cluster located near an event initiated from the sides of the road (a vehicle reverses from the right side of the road into the road). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

non-clustered billboards, 27 more billboards (9 of each cluster). 24 of them were located near a preplanned event and the other three were lactated near the end of a curve (in the condition of low level of load in the road and its sides). Beyond the experimental sessions, each participant reacted to 18 events that occurred on the road and 18 events that initiated from the sides of the road, in each of the four load conditions combinations. Six out of these 18 events occurred in scenarios with no billboard in their vicinity and the other 12 occurred near billboards from one of the clusters (four for each cluster). In total, for any condition of load combination, each participant was encountered: a). six events on the road and six events that initiated from the sides of the road with no billboard in its vicinity; and b). four events on the road and four events that initiated from the sides of the road near a billboard of each cluster of billboards.

3. Results

The following analyses are related to measurements of the drivers' behavior in the face of the preplanned critical events. These measurements include (a) ***Proportion of collisions*** (calculated as the number of collisions divided by the total number of critical events in a given condition). These collisions include only those that occurred up to 10 s after the occurrence of a critical event and therefore were most likely caused by the event. (b) ***The distance*** that the vehicle advanced (reaction distance), measured from the moment the event began until a reaction by the driver. This is a complex index that simultaneously takes into account two important factors related to the driver's behavior: the speed chosen by the driver while driving near the location of the critical event, as well as the driver's reaction time (RT) to the event after detecting it. Specifically, this measurement was calculated as the difference between the longitudinal position of the vehicle when the driver's first reaction to the event was traced and its position when the critical event was launched. The driver's reaction was defined as the first of one of the following: 1) a considerable change in pressure on one of the pedals (throttle or brake). Pedal pressure was measured approximately every 130 ms, and the criterion for change was a ratio of at least 1.4 between the current measurement (n) and its successive measurement (n + 1). 2) Alternatively, a reaction could be defined as a complete lane changing to bypass the event. The reaction initiation in the latter cases was the moment at which a change in the vehicle's lateral position was registered. Cases in which it was impossible to pinpoint the time of reaction were excluded from the analyses, and so were cases in which no reaction was made (hence most likely resulting in collision). In addition, cases with very long distances (more than 60 m) were also excluded from the analyses (only three cases in the entire database).

Four-way ANOVAs, with the within subjects' independent variables "load on the road" (high versus low), "load on the sides of the road" (high versus low), "event location" (on the road versus from the sides of the road), and "billboard cluster" (Loaded, Graphical, or Minimal), were conducted, one for each of these two measurements. Significant interactions were further explored using LSD post hoc analyses. The findings are presented below.

3.1. Proportion of collisions

The two-way interaction between load on the road and billboard cluster was significant [$F(3, 51) = 3.71$, $p < .02$, $\eta p^2 = 0.18$]. To estimate the effect of each billboard cluster on the proportion of collisions, the difference between the proportion of collisions in each condition of road load and billboard cluster in scenarios that included billboards and the proportion of collisions in the equivalent condition of the baseline scenarios, was calculated. If the billboard presence increases the proportion of collisions this difference should be positive and large. Fig. 3 presenting the data on these differences, shows that the presence of Minimal billboards significantly increased the proportion of collisions when the load on the road was high, and that the presence of Graphical billboards significantly increased the proportion of collisions when the load on the road was low.

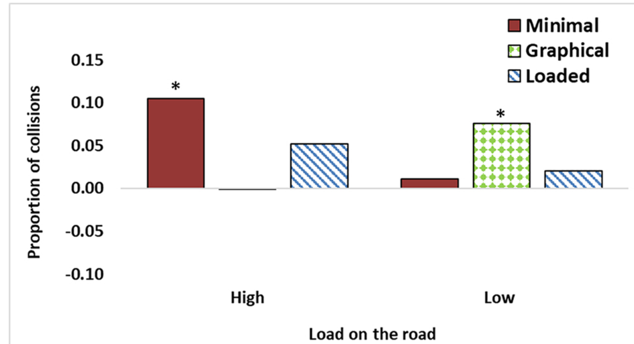

Fig. 3. Differences between the mean proportion of collisions near critical preplanned events in each combination of billboard cluster and load on the road in scenarios with billboards and the mean proportion of collisions in the equivalent condition in baseline scenarios (without billboards), as a function of load on the road and billboard cluster. An asterisk (*) denotes a significant effect of this difference ($p < 0.05$).

The three-way interaction between load on the road, event location, and billboard cluster was significant [$F(3, 51) = 6.15$, $p < .002$, $\eta p^2 = 0.27$]. The difference between the proportion of collisions in each condition of road load, event location, and billboard cluster in scenarios with billboards and the proportion of collisions in the equivalent condition of the baseline scenarios, was calculated. These differences are presented in Fig. 4, showing that the presence of Minimal billboards significantly increased the proportion of collisions when the load on the road was high and the events were initiated from the sides of the road. In addition, the presence of Loaded billboards almost significantly increased the proportion of collisions when the load on the road was high and the events occurred on the road, and when the load on the road was low and the events were initiated from the sides of the road.

3.2. The distance the vehicle advanced (reaction distance)

The main effect of load on the road was significant [$F(1, 17) = 62.2$, $p < .0001$, $\eta p^2 = 0.79$], indicating that a longer mean distance was traveled from the initiation of the event until the first reaction of the driver when the load on the road was low compared to high (19.12 m vs. 14.7 m, respectively). This effect was likely related to the lower median speed in high levels of load on the road (57.9 kph vs. 75.0 kph, respectively). The main effect of load on the sides of the road was also significant [$F(1, 17) = 66.34$, $p < .0001$, $\eta p^2 = 0.80$], indicating that a longer mean distance was traveled with high versus low load on the sides of the road (18.2 m vs. 15.6 m, respectively). Since no difference was found in the median speed of these two conditions (66.6 kph vs. 66.3 kph, for the high and low levels of load on the sides of the road, respectively), it is most reasonable to assume that this effect reflects the demand imposed on the driver's attention by the higher peripheral perceptual load. The main effect of event location was also significant [$F(1, 17) = 17.91$, $p < .0007$, $\eta p^2 = 0.51$], showing a longer mean reaction distance for events initiated from the sides of the road than for events that occurred on the road (19.3 m vs. 14.5 m, respectively). This effect most likely reflects the typically greater attention allocation to the road while driving (e.g., Falkmer and Gregersen, 2005; Shinar, 2008).

The two-way interaction between load on the sides of the road and event location was significant [$F(1, 17) = 7.41$, $p < .02$, $\eta p^2 = 0.30$]. Fig. 5 presenting these data, shows that the distance the vehicle advanced was greater with higher levels of load on the sides of the road. However, this effect was more considerable for events initiated from the sides of the road than for those that took place on the road. This

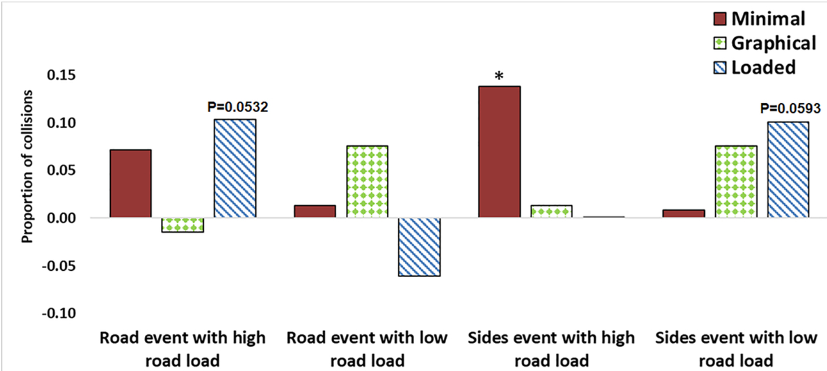

Fig. 4. Differences between the mean proportion of collision near critical preplanned events in each combination of billboard cluster, load on the road, and event location, in scenarios with billboards, and the mean proportion of collisions in the equivalent condition in baseline scenarios (without billboards), as a function of load on the road, event location, and billboard cluster. An asterisk (*) denotes a significant effect of this difference ($p < 0.05$).

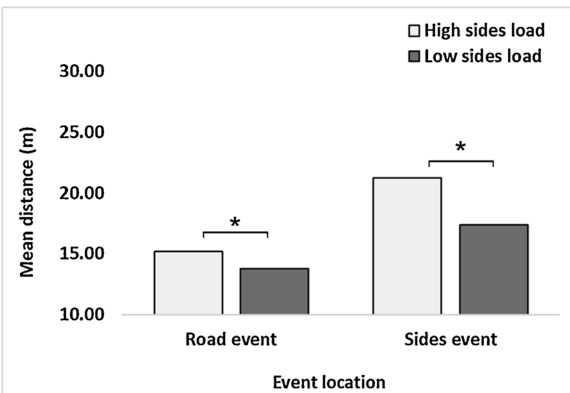

Fig. 5. Mean reaction distance (m) as a function of load on the sides of the road and event location. An asterisk (*) denotes a significant effect of the simple pairwise comparisons ($p < 0.05$).

interaction, once again, is most likely the result of the typical attentional allocation pattern while driving, in which more attention is given to the road than to its sides.

The three-way interaction between road load, load on the sides of the road, and event location was also significant [$F(1, 17) = 10.96$, $p < .005$, $\eta p^2 = 0.39$]. Fig. 6 shows that the reaction distance was greater with higher levels of load on the sides of the road when the load on the road was high in both event location conditions. In contrast, when the load on the road was low, this effect was significant only for events initiated from the sides of the road. This simple pairwise effect was more pronounced compared to the other significant pairwise comparisons in the high road load condition. Thus, this interaction demonstrates the combined harmful effect of the tendency to drive faster with low levels of load on the road and the tendency to allocate less attention resources to the sides of the road.

The two-way interaction between load on the sides of the road and billboard cluster was significant [$F(3, 51) = 5.78$, $p < .002$, $\eta p^2 = 0.25$]. To estimate the effect of each billboard cluster on the mean reaction distance, the difference between mean reaction distance in each condition of sides load and billboard cluster in scenarios that included billboards and in the equivalent condition of the baseline scenarios, was calculated. Once again, if the billboards' presence increases the mean reaction distance this difference should be positive and large. Fig. 7 presenting the data on these differences, shows that the presence of Minimal billboards significantly increased the reaction distance when the load on the sides of the road was low, and that the presence of Loaded billboards significantly increased the reaction distance when this load was high.

The three-way interaction between road load, load on the sides of the road, and billboard cluster was also significant [$F(3, 51) = 3.79$, $p < .02$, $\eta p^2 = 0.18$]. The difference between mean reaction distance in each condition of road load, sides load, and billboard cluster in scenarios with billboards and in the equivalent condition in baseline scenarios, was calculated (Fig. 8). The presence of Minimal billboards significantly increased the reaction distance when the load on both visual field regions was either high or low. In addition, the presence of Loaded billboards significantly increased this reaction distance in the condition of low load on the road with high load on its sides.

Finally, and most importantly with regard to the question examined in the current study, the four-way interaction between road load, load on the sides of the road, event location, and billboard cluster was also significant [$F(3, 51) = 4.59$, $p < .007$, $\eta p^2 = 0.21$]. Fig. 9a presents these data in a radar chart that shows the differences values calculated between each condition's mean reaction distance in the scenarios with billboards and the reaction distance in the equivalent condition in the baseline scenarios. The three colors symbolize the three clusters: red = Minimal, green = Graphical, and blue = Loaded. The dashed black line represents the ***theoretical*** point of zero difference, i.e., this should have been the value if performance with billboards is no different than performance without them. The more the driving performance was harmed by a specific cluster of billboards the more positive and large

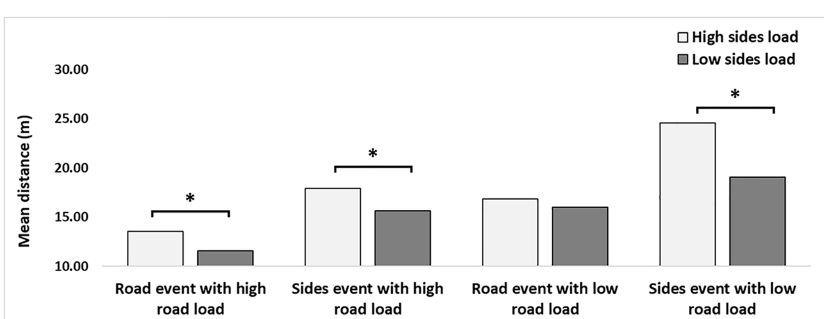

Fig. 6. Mean reaction distance (m) as a function of load on the road, load on its sides, and event location. An asterisk (*) denotes a significant effect of the simple pairwise comparisons ($p < 0.05$).

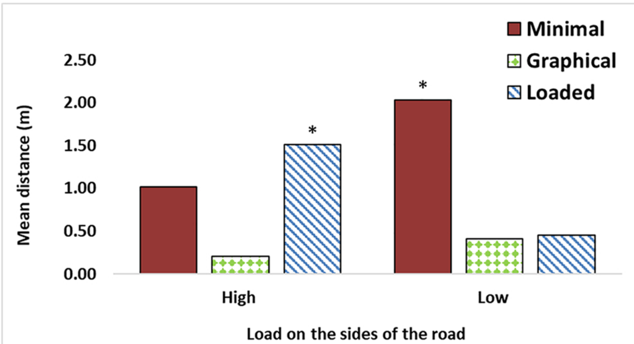

Fig. 7. Differences between the mean reaction distance (m) near critical preplanned events in each combination of billboard cluster and load on the sides of the road in scenarios with billboards and the mean reaction distance in the equivalent condition in baseline scenarios (without billboards), as a function of load on the sides of the road and billboard cluster. An asterisk (*) denotes a significant effect of this difference ($p < 0.05$).

the difference-value would be, and therefore it should be marked a greater reaction distance from this dashed line in the outer direction of the radar chart.

As can be seen in Fig. 9a, the Loaded billboards cluster significantly increased the reaction distance for events that occurred on the road in the condition of low load on the road with high load on its sides, and marginally significantly increased it for events initiated from the sides of the road in the condition of low load in both regions of the visual field. In contrast, the Graphical billboards cluster showed no significant effect in any the various combinations of event location and road load × sides load conditions. Finally, and most importantly given the previous findings of the psychophysical experiment (Marciano and Setter, 2017), the Minimal billboards cluster significantly increased the reaction distance in most of the load combinations when the event was initiated from the sides of the road (except the condition of high road load with low sides load). Surprisingly, the same cluster decreased the reaction distance when the event took place on the road in two of the load combinations, high load on the road with low load on its sides (this effect was marginally significant), and low load on the road with high load on its sides (this was not a significant effect, rather only a trend).

To further explore this surprising effect of the Minimal billboards cluster on the reaction distance measurement, Fig. 9b presents the data of the four-way interaction for the measurement of proportion of collisions. Though this interaction did not reach significance, the relevant pairwise comparisons were analyzed using LSD, in an attempt to figure out the above unpredicted advantage of the Minimal billboards cluster on the reaction distance in the above mentioned conditions. As can be seen in Fig. 9b, this advantage may have resulted from the fact that in these two particular conditions the proportion of collisions was higher in the presence of billboards, suggesting a tradeoff pattern between these two measurements – reaction distance and proportion of collisions. Close examination further shows another condition that exhibits a similar tradeoff of results, the condition of Graphical billboards, for events initiated from the sides of the road, when the load was low in both regions of the visual field. Exploring this specific condition in both radar charts reveals that the reaction distance measurement shows an insignificant advantage for billboard presence (Fig. 9a), while a significant interference is shown in the proportion of collisions measurement (Fig. 9b). Again, this pattern of results may suggest a tradeoff between these two measurements.

4. Discussion

The current study relies on results from a previous psychophysical experiment that classified static advertising billboards as belonging to three different clusters, according to their influence on two concurrent experimental tasks, which mimicked driving related tasks (Marciano and Setter, 2017). The first cluster, termed ***Loaded Billboards***, was characterized as colorful billboards comprised of proportionately small quantities of graphic elements and large quantities of text, which consisted of many letters of all sizes, and also included many logos and information items. The second cluster, termed ***Graphical Billboards***, was characterized as colorful, and contained large quantities of graphic elements and small quantities of text. The third cluster, termed ***Minimal Billboards***, was characterized as having few or no graphic elements, few colors, and a small amount of text with mainly large letters.

To explore the impact of these three clusters in a driving setting closer to real life, a driving simulator study was conducted, using an innovative experimental paradigm that takes into consideration the perceptual load on the road and on its sides (Marciano and Yeshurun, 2015). Driving performance in the presence of billboards from each of these three clusters was compared to driving performance in equivalent baseline scenario conditions where no billboards were presented. Three important factors were systematically manipulated: load on the road (high versus low), load on the sides of the road (high versus low), and the location of preplanned critical events (event on the road versus events initiated from the sides of the road).

The results of the measurements of reactions to critical events show different effects of the three clusters of billboards on driving performance. Graphical billboards had no significant effect on the distance traveled from the initiation of an event until the driver's first reaction in all experimental conditions. This cluster significantly increased the proportion of collisions in one experimental condition only (for events initiated from the sides of the road, when the load was low in both regions of the visual field). This pattern of results generally matches the findings of the previous psychophysical experiment (Marciano and Setter, 2017), in which Graphical billboards had no significant effect on the performance of a tracking task (designed to mimic lane keeping while driving). It also generally confirms the results of a previous driving simulator study, in which most of the billboards could be classified as Graphical (Marciano and Yeshurun, 2012).

In contrast, the Loaded billboard cluster had a greater impact on driving performance. For events that occurred on the road this cluster increased the reaction distance in the condition of low levels of load on the road with high levels of load on its sides, and increased the probability of collisions in the condition of high levels of load on the road

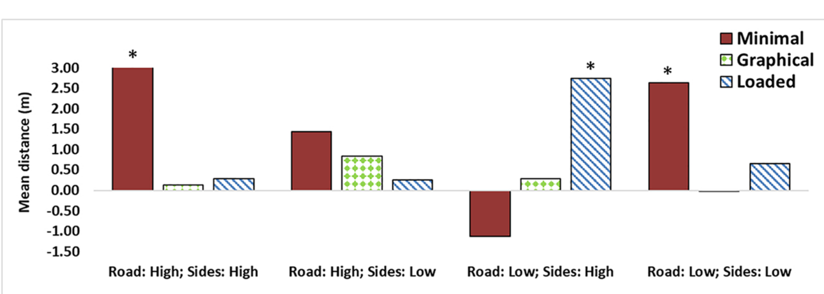

Fig. 8. Differences between the mean reaction distance (m) near critical preplanned events in each combination of billboard cluster, load on the road, and load on the sides of the road, in scenarios with billboards and the mean reaction distance in the equivalent condition in baseline scenarios (without billboards), as a function of load on the road, load on the sides of the road, and billboard cluster. An asterisk (*) denotes a significant effect of this difference ($p < 0.05$).

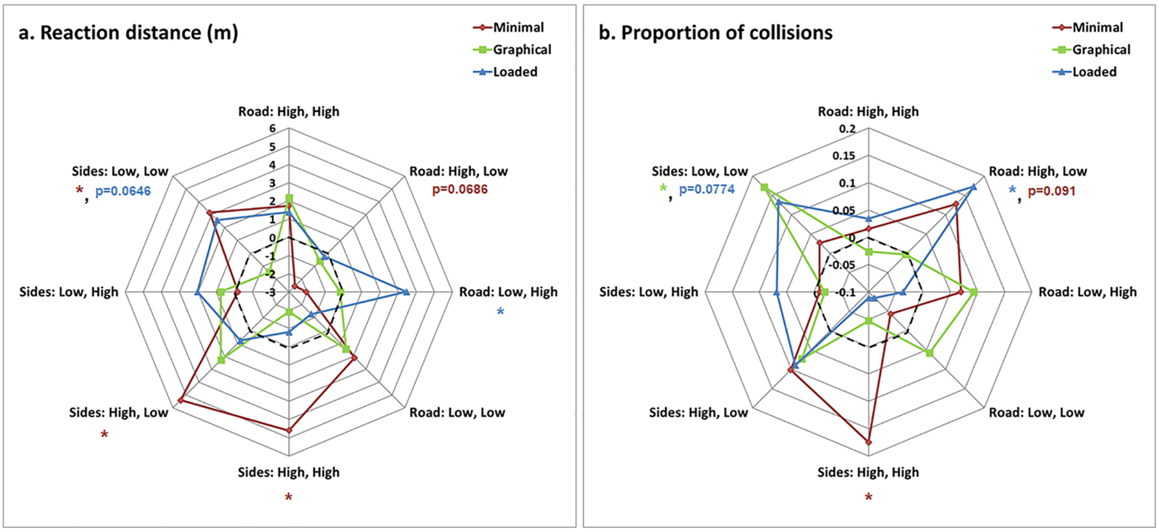

Fig. 9. Differences between a. the mean distance that the vehicle traveled near a critical preplanned event in each condition of load on the road, load on the sides of the road, event location, and billboard cluster, in a scenario with billboards and the mean distance in the equivalent condition in the baseline scenarios; b. the mean proportion of collisions near a critical preplanned event in each condition of load on the road, load on the sides of the road, event location, and billboard cluster, in a scenario with billboards and in the equivalent condition in the baseline scenarios, as a function of load on the road, load on the sides of the road, event location, and billboard cluster. The billboard clusters are presented in the colors: red = Minimal, green = Graphical, and blue = Loaded. The dashed black line represents the theoretical point of zero difference. The specific condition label consists of three words: the first describes the critical event's location, the second describes the load on the road, and the third describes the load on its sides. A colored asterisk (*) or p value equation denotes a significant ($p < 0.05$) or marginally significant effect of the difference in the corresponding color billboard cluster. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

with low levels of load on its sides. For events initiated from the sides of the road when the load was low in both regions of the visual field, the Loaded billboard cluster nearly significantly increased both distance traveled and probability of collisions. This pattern of results also generally matches the findings of the previous psychophysical experiment, in which the Loaded billboard cluster led to the greatest drop in performance on the tracking task. The Loaded billboards are characterized by many textual elements, which consist of many letters of all sizes. A similar effect of billboards with more text on various driving performance measures was reported by others as well (Harasimczuk et al., 2018; Schieber et al., 2014).

Finally, an effect of the Minimal billboard cluster was significantly or nearly significantly evident in four of the eight experimental conditions. For events initiated from the sides of the road this cluster significantly increased the distance traveled for all conditions, except the condition of low levels of load on the road with high levels of load on its sides. In the condition of high levels of load in both regions of the visual field this cluster also increased the probability of collisions. For events that occurred on the road, this cluster nearly significantly increased the probability of collisions in the condition of high levels of load on the road with low levels of load on its sides. Evidently, this effect shows a trade-off pattern with the findings of the reaction distance measurement, where a significant decrease was found. All in all, results of the Minimal billboard cluster do not match the findings of the previous psychophysical experiment, in which these types of billboards least affected both tasks (Marciano and Setter, 2017).

The results of the Loaded and Minimal billboard conditions in the current study are further reinforced when considering the results of a recent real driving setting study that measured eye tracking measurements (Costa et al., 2019). Advertising billboards, characterized as "textural, with a remarkable number of words" (p. 132) led to the longest fixation durations (more than two seconds each), while billboards characterized by the authors as having "rich text content" (p. 132) led to the highest fixation rates. Examining photographs of these billboards reveals that the first type mainly resembles the current study's Loaded cluster and the second the current study's Minimal cluster. Similarly, a driving simulator study found that increasing the number of words in a digital billboard's message resulted in higher off-road eye durations (Schieber et al., 2014).

The Graphical cluster was the least harmful to performance in the driving task in most of the current load conditions. In the context of cognitive psychology, it has been shown that people can recognize a visual scene at a single short glance, a concept termed "the gist of a scene" (Potter, 1976; Potter and Levy, 1969; Oliva, 2005; Oliva & Torralba, 2006). Moreover, with an ERP experiment Thorpe et al. (1996) found that people were able to extract the gist of a scene flashed for an extremely short duration of 20 ms. The remarkable ability of the human visual perception system to extract the visual scene at lightning speed has a strong evolutionary basis, given the lengthy process which underlies its development. This ability is typically viewed as an awareness of the world without the involvement of focused attention (Koch and Tsuchiya, 2007). On the other hand, from an evolutionary perspective, reading text is a quite newer task for humankind, one that demands focused attention and cannot be accomplished in milliseconds. Indeed, in the context of real print advertisements, it has been found that people tend to look at the textual part of an advertisement for longer durations than at its graphic part (Rayner et al., 2001). In addition, increasing the surface size of an advertisement devoted to textual elements over the surface size devoted to graphic elements, was found to increase the attention allocated to the advertisement as a whole (Pieters and Wedel, 2004). In the light of the above discussion, the current findings, in which both billboard clusters that included mainly text (the Loaded and Minimal) affected driving performance much more than the Graphical cluster, are well explained.

Still, the question concerning the finding whereby the Minimal billboard cluster, which hardly affected the tracking task in the psychophysical study (Marciano and Setter, 2017) had the most harmful effect on the drivers' reaction to critical events in the current driving simulator study, begs an answer. Careful examination of the tasks and measurements in both experiments may provide an explanation. The tracking task in the psychophysical experiment was designed to mimic the motor lane keeping component in driving. However, in the current driving simulator study the task required a more complex ability. The measurements of the distance traveled and the proportion of collisions were also more complex than the precision of the hand motor tracking measured in the psychophysical experiment. Reaction distance is an index that takes into account the speed of the vehicle at the initiation of a critical event and the driver's reaction time to the event. The proportion of collisions is an index of the inability to react properly on time, along with the failure to detect the critical event, in cases when the driver did not notice the event at all. These two measurements, which are crucial for safe driving, could not be estimated in the previous psychophysical experiment. Apparently, reading very few words written in large characters on a billboard may not influence the motor aspects of the tracking task (which mimicked lane keeping), as found in the psychophysical experiment, but it has critical ramifications for the other behavioral driving performance measurements in the current driving simulator study. To test this assumption, the data concerning "lane keeping" measurements in locations that were close to a curve were analyzed. If the tracking task in the psychophysical experiment successfully mimicked the lane keeping component in the current driving simulator experiment, then it can be assumed that the Minimal cluster would not affect lane keeping measurement. Indeed, the analyses yielded no difference in the lane keeping measurement between driving in scenarios with any of the billboard clusters and driving in baseline scenarios that did not include billboards.

It can be established that the findings of the current study demonstrate the high importance of testing driving related questions in real or simulated driving settings. Though the psychophysical study was a reasonable and essential method for enabling careful and systematic classification of billboards into clusters, it could not mimic all types of tasks and demands required by a driver when handling a vehicle in a real driving setting. In addition, the current study also shed light on inconclusive data that was reported earlier in the literature. The billboards differently affected driving performance in different road load × sides load × event location × billboard cluster combinations. Previous studies mostly overlooked many of these important factors, resulting in inconclusive findings. As a public policy implication, the current study suggests that Graphical billboards may be the least harmful while driving. This issue will be further discussed in the conclusion section (see below).

4.1. Limitations

Although the current results were encouraging, three limitations deserved to be mentioned. First, using driving simulator enabled to control all experimental aspects of the study in a relatively real driving setting. Former studies found that driving simulator studies are quite valid for assessing real life driving (e.g., Matowicki and Přibyl, 2017; Wynne et al., 2019). Nevertheless, it should be stressed that more ecological field studies are also needed to confirm the current findings in even more realistic settings of real driving. Second, though the current conclusion, for the time being, is that Graphical billboards are the least distracting, there are many more questions to consider before deriving comprehensive concrete guidelines for permissible billboards. For example, the current driving simulator study did not consider many questions related to other aspects of billboards, such as size, lateral position, more advanced advertising technologies (e.g., electronic billboards, video-based billboards, and tri-vision billboards), the effect of billboards on traffic lights perception, their effect on traffic signs perception, etc. Third, the current study, similar to the previous psychophysical experiment, did not relate to the content of the billboards from the perspective of the message that they attempt to deliver. Rather, the billboard clusters were classified according to technical characteristics, such as text and graphic proportions, number of colors, information items, logos, etc. It is important to recognize that some features associated with the content of billboards, for example billboards that contain emotional, sexual, or taboo content, have been found to affect driving performance regardless of the presentation mode (graphics or textual; e.g., Chan et al., 2014; Chan and Singhal, 2013; Maliszewski et al., 2019; Megías et al., 2014).

4.2. Conclusion

When taking into account all the accumulated data from both the psychophysical and the driving simulator studies, it can be concluded that in the current research the Graphical billboards, which include a large quantity of graphics elements with few or no textual elements, were the least harmful while driving. Hence, as a public policy implication, it is suggested that a potential first guideline for permissible billboards can be that Graphical billboards may be the only kind of billboards allowed in the vicinity of roads. However, it is important to mention that based on the results of the psychophysical study, these billboards may interfere with the perception of traffic lights. Therefore, for the time being, it is recommended to avoid placing billboards of this type in the vicinity of intersections that have traffic lights installed. Of course, this question should be further systematically explored with simulator and/or field experiments. Note that limiting billboards of certain characteristics or in specific locations (e.g., near intersections) may be hard to implement in the current sociopolitical conditions in most of the countries around the world. Nevertheless, researchers should continue to study this issue in attempt to suggest more guidelines for permissible billboards, hoping that when critical mass of data will be gathered, the implementation of these guidelines will become more plausible, by applying laws or regulations.

Furthermore, in light of the current findings regarding the effect of Graphical billboards on the proportion of collisions in the case of events initiated from the sides of the road when the load was low in both regions of the visual field, and considering previous results with regard to the content of billboards (e.g., Chan et al., 2014; Chan and Singhal, 2013; Maliszewski et al., 2019; Megías et al., 2014), the effect of Graphical billboards should be examined more profoundly. For example, it is recommended to compare the performance of drivers when encountering different contents of Graphical billboards, e.g., emotional, sexual, or taboo, specifically in the condition of low load on the road and its sides.

Finally, based on the data accumulated in both the psychophysical and the driving simulator studies, it is advisable to altogether avoid billboards with many textual elements, classified here as "Loaded cluster", as well as billboards that contain only few textual elements with no graphical elements, classified here as "Minimal cluster".

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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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.2020.105479.

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