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Perceptual load in central and peripheral regions and its effects on driving performance: advertizing billboards

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Abstract. A broadened version of the perceptual load model was utilized to explore systematically the influence of four variables on driver's behavior: a. levels of load on the road; b. levels of load at the sides of the road; c. event's initial location (on the road vs. at the sides of the road); and d. the presence and size of advertizing billboards. 18 participants participated in two experimental sessions in a driving simulator. One of the sessions contained advertizing billboards and the other session did not. The results indicated that billboards can have a considerable effect on various aspects of driving like the time required responding to a potentially dangerous event or simply the number of accidents occurring during driving, but importantly the effect of billboards on driving was modulated by the levels of perceptual load.

Keywords: Attention, Driver distraction, Visual perception

1. Introduction

This study utilized a broadened version of the perceptual load theory [17], [5] in order to explore drivers' behavior. The study presents a new paradigm based on the orthogonal manipulation of perceptual load in both relevant regions: the road itself and its sides. This paradigm is proposed to be the most suitable way to explore any question about drivers' behavior, and especially questions related to human attention. This claim will be strengthened by the presentation of a driving simulator experiment that explored the influence of advertizing billboards on drivers' behavior.

Allocating attention optimally in a given task involves focusing on relevant stimuli and ignoring irrelevant stimuli. The ability to do so is fundamental in many areas of our life, including driving a car. One model of attentional selection is the perceptual load model [17]. The model claims that the perceptual load in the task at hand modulates selection processes. Perceptual load is a critical factor that determines the extent to which irrelevant information is processed. When the relevant information imposes high load it exhausts the available processing capacity and in turn the processing of irrelevant information is prevented.

Empirical support for the perceptual load model has accumulated during the past 15 years. All of these studies used simple stimuli (e.g. letters) and manipulated the load only in the central task, namely almost always in the central region of the visual field [e.g., 1, 3, 12, 14-19].

Using simple letter stimuli, Marciano and Yeshurun [5] broadened the concept of perceptual load to include load not only in the central regions but also in more peripheral regions of the visual field. They manipulated orthogonally load levels on both relevant (central) and non-relevant (peripheral) regions. Their finding suggested that increasing peripheral load deteriorated performance, but only with low levels of central load. Marciano and Yeshurun [6] found that

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when attention was required not only to central region but to more peripheral regions as well (by presenting a second task located at the periphery), participants were able to recruit additional resources. The implication of this result on driving behavior is clear: drivers can allocate some attentional resources to the peripheral regions while driving, even when the load level on the road is high.

The theoretical framework of perceptual load model can be related to many real-life situations, one of which is driving. Driving takes place at varying load levels that may change rapidly and dramatically during a driving period. The literature on driving and load is quite extensive, most of it focuses on the perceptual load on the road [e.g., 2, 7, 11], or on the cognitive load of the driver [e.g., 4, 8-10, 13, 20]. However, none of these studies explored in a systematic way the manner in which varying load conditions, in various regions of the visual field, affect drivers' performance.

In the current paper an experiment, which took place in a driving simulator, is presented. The load levels on the road and its sides were manipulated to create four distinct combinations: high load on the road with low load on its sides, low load on the road with high load on its sides, low load in both regions, and high load in both regions. Critical events that required a response (e.g., a pedestrian crossing road) were also manipulated, half of them occurred on the road and half of them occurred from its sides. Finally, each participant drove in two different sessions: in one session the critical events took place near a large or a small advertizing billboard, and in the other session no billboards were presented.

2. Method

2.1. Participants

24 participants took part in the experiment, for monetary reward. All were students of the University of Haifa, and had driving experience of at least five years. Two participants were excluded from the sample because they speeded. Another participant was excluded because of a technical problem in his second session. Three more participants were excluded because some of their reactions were uninterpretable. Thus, the statistical analyses included 18 participants, nine women and nine men. The average age was 25.6 years and the average period of having a driving license was 6.9 years.

2.2. Tools

The experiment took place in a partial driving simulator using STISIM software. A Logitech steering system, which included steering wheel and two pedals – gas pedal and brake pedal – was used. The participant sat 2.5 m in front of a wide screen (2.3x3 m). This viewing distance was calculated to ensure that the perceived objects would have a similar visual angle to that in real life. A speaker, providing background sounds was placed behind the participant.

2.3. Scenarios

Four different 23 km long scenarios were programmed. These scenarios simulated a suburban road with two lanes in each direction separated by a road median. Each scenario consisted of four distinct different combination of load on the road and on its sides: high load on the road with low load on its sides (Figure 1b), low load on the road with high load on its sides (Figure 1c), low load in both regions (Figure 1a), and high load in both regions (Figure 1d).

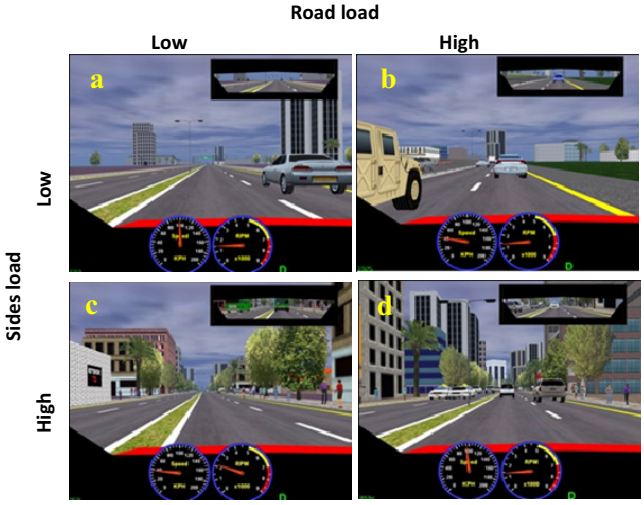


Fig 1: Illustrations of the load combinations: a. low load in both regions; b. high load on the road, low load on its sides; c. low load on the road, high load on its sides; d. high load in both regions.

The load on the road was manipulated via the number and congestion of the vehicles. The load on the sides of the road was manipulated via the number and crowding of pedestrians, the crowdedness of the buildings, the presence of parked vehicles, etc.

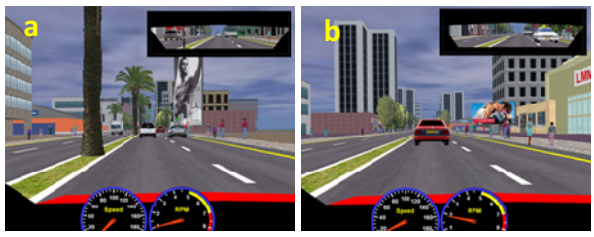
In each scenario 16 critical events were included, eight on the road (e.g. a leading car suddenly slowed

down), and eight from the sides of the road (e.g., pedestrian crossed the road unexpectedly). Events were balanced within the load conditions, in each load combination two events occurred on the road and the other two occurred from its sides.

2.4. Advertizing billboards

Two versions of each scenario were created. One version included advertizing billboards placed at several locations, and the other version was identical but did not include billboards. The billboards were either large (20x8 m, Figure 2a) or small (5x10 m, Figure 2b). The content of all billboards included human images, which filled most of the billboard area, and occasionally a logo or short text.

The billboards were located about 25-50 meters beyond the event's location, on the right side of the road. The presence of the billboards was balanced across the scenario: in each load combination and each event location (road or its sides) each billboard size was presented once. In addition, in order to prevent the association between the presence of billboard and the occurrence of an event, eight more billboards (four large and four small) were presented in locations where no event occurred. In sum, each scenario that contained billboards included 24 billboards, 16 (eight large and eight small) near an event location and eight (four large and four small) in other non-event locations.



ig 2: illustration of advertizing billboards. a. large (20x8 m); b. small (5x10 m).

2.5. Procedure

Each participant participated in three sessions. In the first session the participant drove in a practice scenario of about a half an hour. The next two experimental sessions were longer, about an hour each, and in each session the participant drove in two different scenarios. In one of the sessions the scenarios included advertizing billboards while in the other they did not. The order of the sessions and the order of the scenarios within the sessions were balanced across participants.

In order to encourage the participants to drive at a speed that resembles real life driving, instead of slowing down to prevent accidents, they were informed that they would receive a monetary bonus if they will finish the scenario quickly. However they were also warned that each violation of traffic laws would result in a monetary penalty.

3. Results

3.1. Whole scenario analysis

For every load condition in each scenario of each participant we calculated the vehicle's median velocity and counted the number of accidents that occurred. Thus, these analyses assessed the drivers' behavior in the whole scenario, instead of the behavior during the pre-planned events of the scenarios, which will be presented later on.

3.1.1. Vehicle's Median velocity

A three-way repeated measures ANOVA, road load (low vs. high) x sides of the road load (low vs. high) x billboards presence (with billboards vs. without billboards), was conducted on the median velocity data. The main effect of road load was significant [$F(1, 17)=444.03$, $p<.0001$]; with low load on the road the median velocity was higher than with high load (68.2 kph vs. 47.9 kph, respectively). The main effect of sides load was also significant [$F(1, 17)=57.57$, $p<.0001$]; with low load on the sides of the road the median velocity was higher than with high load (60.5 kph vs. 55.6 kph, respectively). These findings demonstrate the success of the load manipulation. The main effect of the billboards condition was also significant [$F(1, 17)=9.27$, $p<.008$]; driving without billboards was slower than with billboards (57.1 kph vs. 59.0 kph, respectively).

3.1.2. Mean number of accidents

A similar three-way repeated measures ANOVA was conducted on the mean number of accidents. The main effect of road load was significant [$F(1, 17)=12.66$, $p<.003$]; when the level of load on the road was low the mean number of accidents was higher than when the level of load was high (1.33 vs. 0.99, respectively). Apparently the higher velocity in this condition led to more accidents. The main effect

of sides load was marginally significant [F(1, 17)=3.91, p=.0646]; high load level on the sides of the road resulted in a higher number of accidents than with low load level (1.28 vs. 1.04, respectively).

The two-way interaction between road load and sides load was significant [F(1, 17)=4.83, p<.05]. As can be seen in Figure 3 and confirmed by least significant differences (LSD) post hoc analysis, the effect of sides of the road load was modulated by the manipulation of road load: there was no difference in the number of accidents between the two conditions of sides load when the road load was low, however, high sides load raised the number of accidents when road load was high. This result suggests that with high levels of load on the road participants allocated less attentional resources to peripheral information, which resulted in more accidents when more information was presented on the sides of the road.

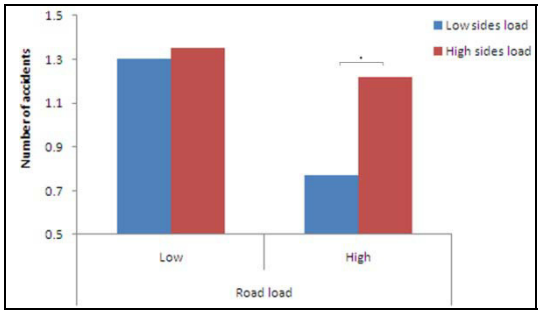


Fig 3: mean number of accidents in the whole scenario as a function of road load and sides load. '*' Significant effect of the simple pairwise comparisons.

3.2. Analysis of reactions to critical events

This analysis took into account only the specific locations where a pre-planned critical event occurred. Three different measures were calculated: 1. Participants' reaction time (RT) to the events; 2. The distance that the car advanced from the moment the event started until a response was made (this is a more subtle measure that takes into account the velocity of the car as well as the reaction of the driver); 3. The proportion of accidents.

3.2.1. RT

A four-way repeated measures ANOVA, road load (low vs. high) x sides of the road load (low vs. high) x event location (road vs. sides of the road) x billboards condition (no-billboards, large billboards, or small billboards), was conducted on mean RT data. The main effect of road load was significant, [F(1, 17)=57.17, p<.0001]; RT was shorter with high load on the road than with low load (0.95 sec vs. 1.33 sec, respectively). This finding probably reflects the extra alertness of drivers while driving in a road with high levels of load. The main effect of sides load was also significant, [F(1, 17)=14.31, p<.0002]; RT was longer with high load on the sides of the road than with low levels of sides load (1.09 sec vs. 0.99 sec, respectively). This effect might suggest that high levels of load on the sides of the road attracted the attention of the participants. The main effect of event location was also significant, [F(1, 17)=268.74, p<.0001]; RTs to events on the road were faster than to events on its sides (0.81 sec vs. 1.28 sec, respectively). This suggests that most of the attentional resources were allocated to the road, as expected.

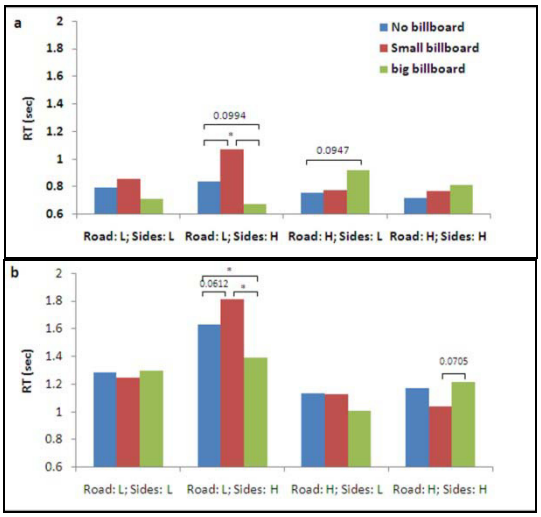


Fig 4: RTs (sec) as function of road load, sides of the road load, billboard's size, and event location. a. events on the road. b. events on the sides of the road'L' stands for low load, 'H' stands for high load. '*' Indicates significant effect of the simple pairwise comparisons.

The main effect of the billboards' condition was not significant. However, the four-way interaction was marginally significant [F(2, 34)=2.71, p=.0812]. LSD post hoc analysis showed that the billboard's size was effective in the condition of low road load with high sides load in both events locations (Figure 4). The presence of small billboards led to signifi-

cantly longer RTs compared with either no-billboards condition or large billboards condition. An unexpected result was that the large billboards decreased the RTs compared with no-billboards condition (marginally significant for events on the road and significant for event on its sides). In contrast, for events that took place on the road (Figure 4Fig 4a), in the condition of high road load with low sides load, the presence of large billboards led to marginally significantly slower RTs compared with no-billboards condition. When the event took place on the sides of the road (Figure 4b), in the condition of high load in both locations, the presence of large billboards also increased RTs compared with small billboards. On all other load conditions there was no effect of billboard's size.

3.2.2. The distance traveled until response initiation

A similar ANOVA was conducted on the data of mean distance that the car passed from the start of the critical event till the initiation of a response. The main effect of road load was significant [$F(1, 17)=138.05$, $p<.0001$]; with high load on the road the mean distance was shorter than with low load (14.7 m vs. 22.1 m, respectively). This effect is quite trivial since high load on the road must lead to slower velocities. The main effect of sides load was not significant, ($F<1$), the distance for both load conditions was about 18 m. This finding might suggest that although the increase in sides load attracted more attention to the sides of the road (as manifested in slower RTs), it did not influence the distance that the car passed during this time, because when the load on the sides increases drivers tend to lower their velocity.

The main effect of event location was significant, [$F(1, 17)=205.34$, $p<.0001$]; the mean distance was shorter for events that took place on the road than for events that took place on its sides (13.4 m vs. 23.4 m, respectively). This finding, as in the equivalent finding for RTs, suggests that most of the attentional resources were allocated to the road.

The main effect of billboards' condition was not significant. However, the four-way interaction was significant [$F(2, 34)=3.31$, $p<.05$]. LSD post hoc analysis revealed that for events that took place on the road only marginally significant difference was found between the different billboard conditions and only with the condition of low load in both locations: the mean distance the car traveled increased when small billboards were presented compared with large billboards (Figure 5a). When the events took place on the sides of the road the billboards' condition was effective in the condition of low road load with high sides load (Figure 5b). The presence of small billboards led to significantly longer distance compared with either no-billboards condition or large billboards condition. In addition, large billboards decreased the distance compared with the no-billboards condition as well as small billboards condition. Finally, an increase in the mean distance when large billboards were presented compared with small billboards was found for the condition of high load in both locations (Figure 5b).

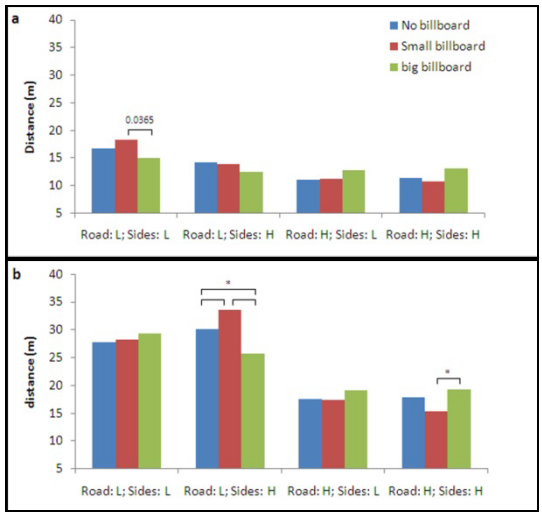


Fig 5: Mean distance that the car passed (m) from eveny onset until response initiation as function of road load, sides of the road load, billboard's size, and event location. a. events on the road. b. events on the sides of the road. 'L' stands for low load, 'H' stands for high load. '*' Indicates significant effect of the simple pairwise comparisons.

3.2.3. Proportion of accidents

A similar ANOVA was conducted on mean proportion of accidents. The main effect of road load was significant [$F(1, 17)=22.15$, $p<.0003$]; with low load on the road the mean proportion of accidents was higher than with high load (0.33 vs. 0.20, respectively). This can be due to the higher velocity when the load on the road was low. The main effect of sides load was significant, [$F(1, 17)=14.53$, $p<.002$]; the proportion of accidents was higher when the sides load was high than it was low (0.31 vs. 0.22, respectively). This finding, combining with the findings of RT and distance data, suggests that the increase in

sides load created more distractions. On the one hand these distractors led to slower velocities, but on the other hand they also slowed RTs to the critical events and increased the probability for accident.

The main effect of event location was significant [F(1, 17)=36.15, p<.0001]; there were less accidents when the events took place on the road than when they took place on its sides (0.17 vs. 0.31, respectively). This finding, again, suggests that most of the attentional resources were allocated to the road, which left the sides more vulnerable when a sudden event occurred.

The main effect of billboards condition was also significant [F(1, 17)=5.73, p<.008]; LSD post hoc analysis revealed that with large billboards there were less accidents than with small billboards (0.21 vs. 0.33, respectively, p<.05). The proportion of accidents in the no-billboards condition (0.26) did not differ significantly from the small or the large billboards conditions.

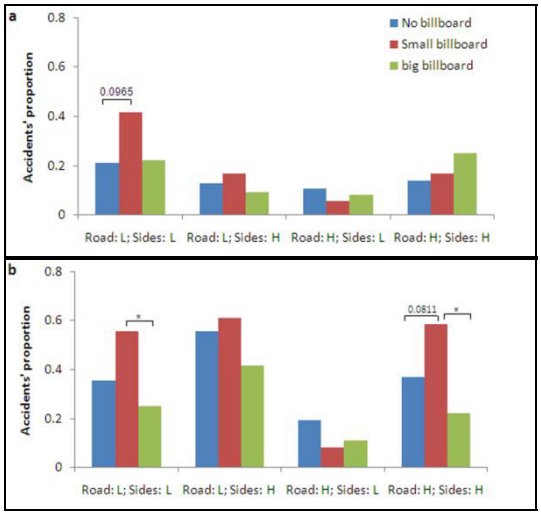


Fig 6: Mean accidents' proportion as function of road load, sides of the road load, billboard's size, and event location. a. events on the road. b. events on the sides of the road. 'L' stands for low load, 'H' stands for high load. '*' Indicates significant effect of the simple pairwise comparisons.

The four-way interaction was not significant (F<1). Nevertheless, LSD post hoc analysis was conducted to test the simple pairwise comparisons. For events that took place on the road when load was low in both regions, this analysis revealed a marginally significant increased in the proportion of accidents with small billboards compared with the no-billboards condition (Figure 6a). When the events took place on the sides of the road (Figure 6b), and the load level was the same in both regions (either low or high), large billboards decreased significantly the accidents proportion compared with small billboards condition. In addition, when the load was high in both regions a marginally significant increase in accidents proportion was found with small billboards compared with the no-billboards condition.

3.2.4. Response to events from the road median

In order to make the scenarios more diverse, one side event in each scenario was created in a different way: it took place on the road median instead of on the right side of the road. It is important to note that when the event initiates in the road median area the level of load on the sides of the road is much less relevant. This is because the load manipulation was only located on the right or left sides of the lanes, while on the median there was no load at all. These four events (one in each scenario) were not included in the analyses presented above.

In this section we analyze these four 'road median' events. The importance of this analysis is that it seems to shed a light on the quite surprising finding that often large billboards improved performance compared to the no-billboards condition.

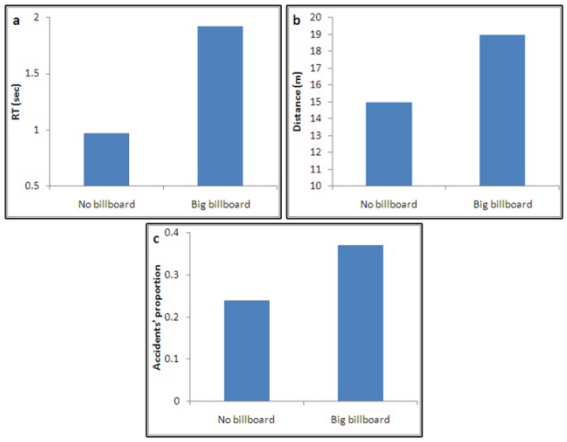


Fig 7: a. mean RT (sec); b. mean distance (m) that the car advanced since the onset of the event until a response was initiated; and c. mean accidents' proportion, as function of the presence of large billboards compared with no-billboards condition, for the four events that started from the road median.

What can be seen in the results of these four road median events is that when the event took place not near the billboard, it reduced the drivers' performance

in all measures: RT (Figure 7a), distance (Figure 7b), and proportion of accidents (Figure 7c).

4. Discussion

The current study explored the combined influence of perceptual load level on the road, perceptual load level at the sides of the road, the location of critical events, and the presence and size of advertizing billboards, on drivers' performance within a driving simulator.

The presence of the billboards increased the velocity in all the load combinations' conditions. This finding suggests that the billboards attracted the attention of the participants, increasing their mental load, and leaving less spare capacity to monitor the velocity of the car. Recarte and Nunes [13] reported a similar influence of mental load on speeding. They found that driving velocity increased when a second mentally demanding task was employed.

The load combination condition that was most vulnerable to the presence of billboards was the condition of low load on the road and high load on its sides. In this condition, the presence of small billboards increased RT – the time required to respond to a critical event – for both types of events, and increased the distance the car traveled from the start of the critical event until the initiation of the response, for events occurring on the road. This finding suggests that when the load level on road is low, more attentional resources can be allocated to deal with the high levels of load on the sides of the road, resulting in more substantial deployment of attentional resources to the billboard.

Two conditions were more prone to accidents, as a result of the presence of the small billboards. The first was the condition of low load in both regions. Most likely, this result is the outcome of the higher driving velocity when the road and its sides are open. The second was the condition of high load in both regions, but here the effect was restricted to events initiating from the sides. This finding might suggest that when load levels across the visual field are high, the addition of billboards pushed to the limit the ability of the drivers to spread their attention, and reduced their ability to respond to sudden events, especially those that started from the sides of the road.

The influence of large billboards was minimal. Only a marginally significant effect was found in the condition of high road load with low sides' load, for events occurring on the road. Large billboards increased RTs in comparison to the no-billboards condition. Some of the trends found with large billboards, especially those related to events that start from the sides of the road, actually decreased RT, the distance traveled, or the proportion of accidents. This may appear counterintuitive, but a possible explanation is offered by the outcomes of the separate analysis performed on the four events that started from the road median. For these four events, RT, distance, and accidents' proportion were higher with large billboards than with the no-billboards condition. This suggests that the presence of large billboards did not really improve drivers' performance. The seemingly improved performance with critical events that started from the sides of the road might be due to the fact that these events occurred near a billboard that was placed at the right side. In these cases, the attention captured by the adjacent billboard might have helped the drivers to perceive the critical event. In contrast, when the events started from the road median (i.e., a location that is relatively far from the billboard), the attentional capture by the billboard decreased performance.

Above all, the experiment showed the importance of manipulating the perceptual load on the road and on its sides, and the location of critical events. The influence of the billboards on driving performance, when the various performance measurements are averaged across the different conditions has no clear pattern. Namely, without the manipulations of these three variables (road load, sides of the road load, and event's location) most of the billboard effects described above would have not been found.

To sum up, this study showed that the presence of advertizing billboards, of both sizes, influenced the behavior of participants. When billboards were present they attracted the participants' attention, resulting in an increased tendency to drive faster. This attentional capture interfered with the ability of the participants to distribute efficiently their attentional resources between the road and its sides, resulting in less effective search for critical events. This process led to a less efficient response to such events, which on some occasions ended in an accident.

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