The emotional side of cognitive distraction: implications for road safety

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Abstract

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. However, little is known about the role of emotional distraction on driving, despite evidence that attention is highly biased toward emotion. In the present study, we used a dual-task paradigm to examine the potential for driver distraction from emotional information presented on roadside billboards. This purpose was achieved using a driving simulator and three different types of emotional information: neutral words, negative emotional words, and positive emotional words. Participants also responded to target words while driving and completed a surprise free recall task of all the words at the end of the study. The findings suggest that driving performance is differentially affected by the valence (negative versus positive) of the emotional content. Drivers had lower mean speeds when there were emotional words compared to neutral words, and this slowing effect lasted longer when there were positive words. This may be due to distraction effects on driving behavior, which are greater for positive arousing stimuli. Moreover, when required to process non-emotional target stimuli, drivers had faster mean speeds in conditions where the targets were interspersed with emotional words compared to neutral words, and again, these effects lasted longer when there were positive words. On the other hand, negative information led to better memory recall. These unique effects may be due to separate processes in the human attention system, particularly related to arousal mechanisms and their interaction with emotion. We conclude that distraction that is emotion-based can modulate attention and decision-making abilities and have adverse impacts on driving behavior for several reasons.

Keywords: attention; arousal; distraction; driving; dual-task; emotion

1. Introduction

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. In 2009, it accounted for 16% of all fatal crashes and 20% of injury crashes (National Highway Traffic Safety Administration, 2010). According to the 100-Car Naturalistic Driving Study, 22% of crashes and near crashes during the study period was associated with a driver being distracted by an object, event, or person inside or outside the vehicle (Dingus et al., 2006; Klauer et al., 2006). To date, the majority of studies have examined driver distraction from cell phone conversations (e.g., Strayer and Johnston, 2001); secondary tasks, such as eating and adjusting in-vehicle controls (e.g., Stutts et al., 2005); and roadside advertisements (e.g., Young et al., 2009); however, little is known about the role of emotional distraction on driving. This is important as prior studies have shown that emotional distracters can disrupt task performance (Holahan et al., 1978; Johnston and Cole, 1976).

Driver distraction is often defined as any activity that diverts a driver’s attention away from the task of driving toward a task-irrelevant object or event, often resulting in impairment in the ability to drive safely and effectively. It has been suggested that the impairments are related to a decrease in the driver’s ability to recognize and be aware of information required for critical decisions and reactions to be carried out (Ranney et al., 2000; Stutts et al., 2001). Some of the main sources of the distraction are outside objects or persons, in-car eating and drinking, cell-phone use, and adjusting dashboard controls.

Roadside billboards often provide advertising in major traffic areas where there is an increased risk for motor accidents. These billboards are largely visible and feature conspicuous images and/or slogans to attract drivers. Several studies have examined whether roadways with billboards are associated with more traffic accidents, however results have been inconsistent.

Some naturalistic studies have found no correlation between number of billboards and accident rates (Blanche, 1956) and no correlation between the number of billboards and driving performance (Lee et al., 2003). However, one 'before and after' naturalistic study found that ostentatious advertisements located at sharp bends increased accident rates (Ady, 1967). This suggests that conspicuous distractions located at roadways that require considerable awareness or judgment can influence driving performance.

More controlled experimental studies have revealed that reaction time is slowed when participants are to press a button in response to a target while being distracted by advertisements (Holahan et al., 1978; Johnston and Cole, 1976). Furthermore, performance decreases with number of distracters and proximity (i.e., the closer the distracting advertisements are to the target, the slower the response). Recent simulated driving studies have also demonstrated that roadside billboards have a negative impact on driving as measured by more lane deviations, more eye glances toward the billboards, and impaired memory recall of traffic signs compared to billboards (Bendak and Al-Saleh, 2010; Crundall et al, 2006; Young et al., 2009).

Overall, these observations establish that roadside billboards can visually and cognitively affect drivers (for a review, see Wallace, 2003). Two theories have been proposed to account for the negative impact of billboards on driving performance. According to the low arousal theory, when drivers are under-aroused (e.g., driving along a quiet roadway), roadside billboards "pop-out" to distract from the driving environment. In other words, when an unexpected stimulus appears, attention is immediately diverted to it at the cost of performance of the primary task. The second theory proposes that when drivers are over-aroused (e.g., watching vigilantly for a pedestrian), roadside billboards distract by providing "visual clutter." The greater the clutter, the more likely it will interfere with the driver's visual search of the driving scene (Wallace, 2003).

This has been supported by visual search tasks where reaction time of a target is slowed with number of distracters (Holahan et al., 1978; Johnston and Cole, 1976).

The few findings on emotional driving have shown that negative affect provokes risky and aggressive behavior, as measured by speeding and more lane wanderings (Dula and Geller, 2003); however, no study has examined the impact of emotional distractions that are *external* to the driver. This is important as the arousal level of emotional stimuli is closely linked to attention, so that a greater share of attentional resources are allocated to emotional than neutral items during processing (Schimmack, 2005; Talmi et al., 2008; for a review, see Vuilleumier, 2005). For example, findings from the emotional Stroop task have demonstrated that response times are slower when naming the ink color (e.g., red) of an emotional word (e.g., *war*) compared to a neutral word (e.g., *table*), suggesting that interference is occurring from the emotional word, despite efforts to suppress its meaning. Several studies have also established that emotional stimuli enhances memory due to prioritized attention to these items during encoding (Kensinger and Corkin, 2003; Sharot and Phelps, 2004; Talmi et al., 2008). Following a delay, more emotional items are recalled and recognized than neutral items, linking the emotional enhancement of memory effect to increased arousal and attention to these items.

While some studies have failed to find performance differences between the attentional effects of negative and positive stimuli, Pratto and John (1991) proposed that the two types of stimuli are evaluated differently. According to the categorical negativity theory, because negative stimuli are more critical for survival, we have evolved to detect these stimuli more strongly. As a result, negative stimuli attract more attention than positive and neutral stimuli. In the emotional Stroop task, it was found that negative words produced longer response times and better memory recall than positive words, suggesting that negative and positive stimuli may have different influences on attention (Pratto and John, 1991). One assumption is that negative stimuli may trigger more attentive, but time-consuming, evaluation, resulting in slower response times and better accessibility for memory (negativity bias) (Taylor, 1991; for a review, see Baumeister et al., 2001).

Together, these findings demonstrate that a) emotional stimuli produce an overall arousal effect that is closely linked to attention and, b) detection of negative and positive stimuli can differentially affect attention. This has real-world impact on driver distraction as emotional billboards can enhance the attention-arousal mechanism of emotion to increase the risk of motor accidents. For example, seeing a negative emotional billboard can result in greater diversion of attention away from the driving environment than seeing a neutral billboard. Moreover, it has been suggested that emotional information can have carry-over effects into cognitive behavior that directly influence judgments and decision-making processes (Lerner and Tiedens, 2006). Thus, another important issue to address is whether the effects of emotional information have immediate and/or lingering effects on human performance.

Accordingly, the objective of our study was to address the impact of emotional distractions by using a dual-task paradigm to examine the distracting effects of emotional information on simulated driving performance. We ran participants through four conditions: one control condition, where they drove without billboard distraction, and three experimental conditions where: 1) they drove with non-emotional (neutral) words on billboards, 2) they drove with negative emotional words on billboards, and 3) they drove with positive emotional words on billboards. In the dual-task scenarios, participants were also required to respond to target (non-emotional) words that were animal names. After all conditions were completed, we ran a surprise free recall task where participants typed out as many words as they could from memory.

Our chief measures of interest were driving performance, billboard response performance, and recall performance.

The first hypothesis is that we expect the following driving performance measures (see section 2.3 for details): overall course velocity, lane position in the form of root mean square error (RMSE), and steering wheel rate and angle, both in the form root mean square error (RMSE), will be most impaired in the presence of emotional words, followed by moderate impairment in the presence of neutral words, and lower impairment in the presence of no words. Because emotional words are highly arousing, we predict these items will attract attention away from the driving scene at an increased cost of driving performance compared to neutral words. The second hypothesis is that we expect that driving performance will differ in the presence of negative words compared to positive words due to their differential influences on attention. We predict that negative words will draw more attention away from driving, resulting in slower driving speed and response times than positive words. The third hypothesis is that we expect that there will be differential carry-over effects from the emotional information that impacts simulated driving performance dependent upon the valence of the information and the distance traveled after encountering the emotional billboard. The fourth hypothesis is that we expect that memory recall for emotional words will be better than memory recall for neutral words due to the memory enhancement effect of emotional items. Furthermore, because attention is drawn more strongly towards negative than positive words, we predict that more negative words will be recalled than positive words.

2. Method

2.1. Participants

30 students (M = 21.4, SD = 2.5) from the University of Alberta participated in return for an honorarium. Participants were recruited via posters placed on campus. All were in the age range of 18 to 30 years old and had normal to corrected-to-normal vision. Data was excluded from eight participants because they did not drive to criterion (see section 2.4 for details).

2.2. Stimuli and apparatus

60 English nouns served as stimuli, with 48 words varying in valence. 16 were neutral (e.g., clock, fabric, pencil), 16 were negative emotional (e.g., abuse, reject, stress), and 16 were positive emotional (e.g., glory, humor, joy). Negative words were selected to be low in valence and high in arousal, while positive words were selected in be high in valence and high in arousal. The three categories were matched across valence for word frequency, and all negative and positive words were matched for arousal, which differed from neutral words. Outside of the three categories, there were 12 animal names (e.g., cat, lion, snake) that acted as target words that participants were instructed to respond to. All 60 words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999). See Table 1 for details on the word parameters and the appendix for a list of the words used.

The proprietary driving simulator from STISIM Drive™ (Systems Technology, Inc.) was used to create high-resolution driving scenarios. The simulator comprised of a 22” widescreen computer monitor, steering wheel, and gas and brake pedals.

2.3. Design

All participants completed two practice runs and four separate conditions (one control and three experimental) in one hour.

The simulated road created for the practice run was a 6.4 km-long rural scenario, consisting of straight roads and winding turns, with one lane in each traffic direction. To measure situational awareness, four pedestrians crossing the road, three stop signs, and two traffic lights were added. Pedestrians were programmed to cross the road when the participant's vehicle was within 200 m of the pedestrian. Traffic lights were programmed to turn red when the participant's vehicle was within 200 m of the traffic light. The simulations also included other visual stimuli such as buildings, trees, and other vehicles (cars, trucks, and motorcycles) that occasionally came in the opposite direction.

For the non-practice runs, the 6.4 km-long scenario was shortened to a 4.4 km-long scenario, containing three pedestrians crossing the road, two stop signs, and two traffic lights. There were four conditions in total, with the order counterbalanced across participants using a Latin-square design:

1.) In the control condition, participants drove without billboard distraction.

2.) In the neutral condition, participants drove with 16 non-emotional words and four animal words on billboards.

3.) In the negative condition, participants drove with 16 negative emotional words and four animal words on billboards.

4.) In the positive condition, participants drove with 16 positive emotional words and four animal words on billboards.

The billboards were placed on the right hand side of the road every 200 m and their content was readable to the driver when the vehicle was approximately 60 m in front of each sign. One billboard was placed before a bend, three were placed after a bend, and the rest were placed on straight paths. All target, neutral, and emotional words were randomly inserted into each driving condition.

Four driving performance measures were monitored. *Mean speed* was defined as the average longitudinal velocity, in km/h. *RMSE lane position* was defined as the root mean square deviation of the driver's lateral position with respect to the center dividing line, measured in meters. *RMSE steering wheel rate* was defined as the root mean square deviation of how fast the driver was turning the steering wheel when maneuvering, in degrees/sec. *RMSE steering wheel angle* was defined as the root mean square deviation of far the driver is turning the steering wheel with respect to 0 degrees, measured in degrees. Response times and error rates of the animal targets were logged for each condition. Response times were calculated from the time the target billboard could be read to the time the participant pressed the response button. The proportion of words recalled was also calculated for each condition.

2.4. Procedure

Participants were first familiarized with the driving simulator by completing the practice run twice. A two minute break was given between runs. Participants were instructed to pay attention to pedestrians, stop signs, and traffic lights, and to drive between 40 to 80 km/h to ensure that no participants were driving too slow or too fast. The experimenter sat in the same room during the practice runs to ensure the participant was driving to criterion, which was to keep a mean speed between 40 to 80 km/h and a RMSE lane position between 0.3 m to 0.4 m at the end of the second run.

Following the practice runs, participants completed four conditions (control, neutral, negative, and positive). Participants were instructed to press a button on the steering wheel using their left hand as quickly as possible when an animal target word came into view. A mandatory two minute break was given after each condition. Immediately after the simulation, a surprise recall test for the words was administered. Participants were instructed to recall by typing out as many words as possible from all conditions within three minutes.

3. Analyses

All effects were considered statistically significant based on the alpha level of 0.05.

3.1. Performance averaged over the entire simulation

All of the performance measures data was analysed with a one-way repeated measures analysis of variance (ANOVA) with four levels (driving condition: control, neutral, negative, and positive). All of the target response data was analysed with a one-way repeated measures ANOVA with three levels (driving condition: neutral, negative, and positive). All of the recall data was analysed with a one-way repeated measures ANOVA with four levels (word type: targets, neutral, negative, positive).

3.2. Performance averaged over particular road sections with or without billboards (targets excluded)

To further explore driving performance in this experiment we divided the roadway into four different sections for analyses: a) A 60 m pre-billboard section, where a billboard appeared in sight but the word on it could not be read, b) A 60 m billboard section, where the word on the billboard could be read, c) A 60 m post-billboard section that followed after the billboard was out of sight, and d) An extended 80 m post-billboard section that continued up to the next pre-billboard section. Thus, the two post-billboard sections were 140 m in total length.

For each participant, the mean driving performance was calculated for each section and each billboard, before being averaged across sections and billboards. Overall means were then averaged across participants. There were 16 billboards in total, excluding target words.

All of the performance measures data were analysed with a 4x3 repeated measures ANOVA containing the factors road section (pre-billboard, billboard, immediate post-billboard, extended post-billboard) and billboard word type (neutral, negative, positive).

3.3. Performance during road sections with target billboards only

The same analyses as in the previous section (3.2) were performed on the data from road sections that contained target (animal) words only.

4. Results

4.1. Driving performance data

A one-way repeated measures ANOVA revealed a significant main effect of condition on mean driving speed (MDS) [$F(3,87) = 3.98$, $p<0.01$]. Planned contrasts revealed that this effect was due to a higher MDS in the driving alone condition compared to the neutral words ($p<0.005$) and negative words ($p<0.05$) conditions. There was also an increase in MDS in the positive words condition compared to the neutral words condition ($p<0.05$). See Fig. 1 for participants' MDS within each driving condition.

A one-way repeated measures ANOVA revealed a significant main effect of condition on RMSE steering wheel rate [$F(3,87) = 2.89$, $p<0.05$]. Planned contrasts revealed that this effect was due to a higher RMSE steering wheel rate in the emotional words condition compared to the neutral words condition ($p<0.05$). See Fig. 2 for participants' mean RMSE steering wheel rate within each driving condition.

A one-way repeated measures ANOVA revealed no main effect of condition on RMSE steering wheel angle [$F(3,87) = 1.63$, $p=0.189$]. However, planned contrasts revealed that there was an effect due to a higher RMSE steering wheel angle in the negative words condition compared to the neutral words condition ($p=0.05$). See Fig. 3 for participants' mean RMSE steering wheel angle within each driving condition.

A one-way repeated measures ANOVA revealed no main effect of condition on RMSE lane position [$F(3,87) = 0.79$, $p=0.51$]. However, planned contrasts revealed that there was an effect due to a higher RMSE lane position in the driving alone condition compared to the neutral words condition ($p<0.05$). There was also an increase in RMSE lane position in the negative words condition compared to the neutral words condition ($p<0.05$). See Fig. 4 for participants' mean RMSE lane position within each driving condition.

4.2. Target response data

No differences were found in mean error rates (1.7% for the neutral condition, 2.5% for the negative condition, and 4.2% for the positive condition). A one-way repeated measures ANOVA revealed a significant main effect of condition on response times [$F(2,58) = 10.19$, $p<0.001$]. Planned contrasts revealed that this effect was due to faster response times in the positive words condition compared to the neutral words condition ($p<0.01$) and the negative words condition ($p<0.001$). Additionally, response times were faster in the neutral words condition compared to the negative words condition ($p<0.05$). See Fig. 5 for participants' mean response times within each driving condition.

4.3. Memory recall data

A one-way repeated measures ANOVA revealed a significant main effect of condition on memory recall [$F(3,87) = 64.1$, $p<0.001$]. Planned contrasts revealed that this effect was due to more target words being recalled than neutral and emotional words combined ($p<0.001$). Further analyses revealed that more emotional words were recalled than neutral words ($p<0.001$), with negative words showing higher recall than positive words ($p<0.005$). The mean proportion of words recalled were: 0.41 (SD: 0.12) for target words; 0.22 (SD: 0.13) for negative words; 0.13 (SD: 0.11) for positive words; and 0.05 (SD: 0.07) for neutral words.

4.4. Road sections with or without billboards (targets excluded)

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on mean driving speed (MDS) [$F(6,174) = 23.1$, $p<0.000$]. Planned contrasts revealed that this effect was due to a slower MDS in the negative ($p<0.05$) and positive words ($p<0.005$) conditions compared to the neutral words condition in the billboard sections. In the immediate post-billboard sections, MDS was slower in the positive words condition compared to the neutral words ($p<0.000$) condition. In the extended post-billboard sections, there was an effect of slower MDS in the positive words condition compared to the neutral words ($p<0.001$) and negative words ($p<0.005$) conditions. Overall, we observed that MDS was slower in response to emotional billboards compared to neutral in the billboard and immediate post-billboard sections, while MDS was slower in response to positive billboards compared to both the negative and neutral billboards in the extended post-billboard sections (see Fig. 6).

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on RMSE steering wheel angle [$F(6,174) = 3.14$, $p<0.01$]. Planned contrasts revealed that this effect was due to a higher RMSE steering wheel angle in the negative words ($p<0.05$; $p<0.005$) and positive words ($p<0.000$; $p<0.05$) conditions compared to the neutral words condition in the pre-billboard and billboard sections, respectively. The means for the billboard sections were: 3.76 (SD: 3.42) in the positive words condition; 3.14 (SD: 1.17) in the negative words condition; and 2.36 (SD: 0.44) in the neutral words condition. Overall, we observed that RMSE steering wheel angle was higher in response to emotional billboards compared to neutral before and during billboard presentation.

A 4x3 repeated measures ANOVA revealed a significant main effect of road section on RMSE lane position [$F(6,174) = 0.34$, $p<0.05$]. Planned contrasts revealed that this effect was due to a higher RMSE lane position in the pre-billboard sections compared to the immediate post ($p<0.005$) and extended post-billboard ($p<0.05$) sections. RMSE lane position was also higher in the billboard sections compared to the immediate-post billboard sections ($p<0.05$), and higher in the extended post-billboard sections compared to the immediate post-billboard sections ($p<0.005$). Overall, we see that RMSE lane position is higher before and during billboard presentation compared to the immediate-post billboard sections. RMSE lane position is also higher in the extended-post billboard sections compared to the immediate-post billboard sections.

4.5 Road sections with target billboards only

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on mean driving speed (MDS) [$F(6,174) = 43.9$, $p<0.000$]. Planned contrasts revealed that this effect was due to a higher MDS in the negative words ($p<0.000$; $p<0.001$; $p<0.000$) and positive words ($p<0.000$; $p<0.000$; $p<0.000$) conditions compared to the neutral words condition in the pre-billboard, billboard, and immediate post-billboard sections, respectively. In the extended post-billboard sections, there was an effect of a higher MDS in the positive words condition compared to the neutral words ($p<0.000$) and negative words ($p<0.000$) conditions. Overall, we observed that MDS was greater for target billboards in the emotional words conditions compared to the neutral words condition in all road sections, except the extended post-billboard sections. In the extended post-billboard sections, MDS was greater for target billboards in the positive words condition compared to the neutral and negative words conditions (see Fig. 6).

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on RMSE steering wheel angle [$F(6,174) = 28.9$, $p<0.000$]. Planned contrasts revealed that this effect was due to a lower RMSE steering wheel angle in the negative ($p<0.001$) and positive words ($p<0.000$) conditions compared to the neutral words condition in the pre-billboard sections. RMSE steering wheel angle was also lower in the positive words condition compared to the negative words condition in the pre-billboard sections ($p<0.001$). In the billboard sections, there was an effect of lower RMSE steering wheel angle in the positive words condition compared to the neutral words condition ($p<0.000$). The means for the billboard sections were: 0.40 (SD: 0.40) in the positive words condition; 1.80 (SD: 5.57) in the negative words condition; and 3.22 (SD: 0.39) in the neutral words condition. Overall, we observed that RMSE steering wheel angle was lower in response to target billboards in the emotional words (particularly positive) conditions, compared to the neutral words condition, before and during billboard presentation.

A 4x3 repeated measures ANOVA revealed no significant interaction or main effects of road section or word type on RMSE lane position.

5. Discussion

The purpose of this study was to examine the potential for driver distraction from emotional information presented on roadside billboards using a dual-task paradigm. This purpose was achieved using a driving simulator and three different types of emotional information. The main findings suggest that driving performance is differentially affected by the valence (negative versus positive) of the emotional content. Moreover, these unique effects are likely due to separate processes in the human attention system, particularly related to arousal mechanisms and their interaction with emotion. It has been well-established that emotional stimuli can modulate the allocation of attention (Easterbrook, 1959), and more recently, it has been suggested that emotion can impact other cognitive control mechanisms, such as working memory and decision-making (Johnson et al., 2005). Based on our findings, it appears that there are at least two mechanisms of emotion-related distraction that have the potential for impact on real-world driving performance. Furthermore, driving performance varied across different sections of the driving scenario relative to the physical position of the billboards, and also depended upon whether the driver responded (targets) to the billboard information or did not respond (non-targets).

The recall task showed that memory performance was highest for target words compared to all other conditions of words. This was expected since drivers needed to attend as well as respond to these specific words. The results also showed that words describing positive and negative emotions were more likely to be recalled than neutral words. This is consistent with previous research showing enhanced attentional processing of emotional information (Kensinger and Corkin, 2003; Sharot and Phelps, 2004; Talmi et al., 2008). One possible interpretation of this finding is that drivers were taking their eyes off the road for an extended period of time in order to process the emotional billboards at the expense of processing information that was more critical for safe driving. In a real driving scenario, this could cause drivers to lose control of their vehicle and/or fail to detect other relevant roadway information. Interestingly, more negative valence words were recalled than positive valence words supporting the idea that negative stimuli received more attention than positive stimuli (Ohira et al., 1998; Robinson-Riegler and Winton, 1996). However, faster target responses were observed during blocks of positive emotional words compared to negative and neutral words. Thus, while positive words do not capture attention to the same degree as negative words, they result in quicker responses. This is consistent with other studies showing that positive words (Feyereisen et al., 1986; Pratto and John, 1991; Stenberg et al., 1998) and positive pictures (Lehr et al., 1966; Leppänen et al. 2003) are associated with faster manual responses than negative and neutral items. Other studies have also shown that negative stimuli hold attention for a longer period of time, which can also manifest in slower response times (for a review, see Baumeister et al., 2001; Fiske, 1980; Pratto and John; 1991; Taylor, 1991). Overall, drivers had lower mean speeds for the entire driving scenario when there were negative and neutral words on the billboards. However, the positive words were associated with an increase in mean speed. Other related research has shown that positive emotions are associated with better and faster physical performance, including jumping higher or running faster, compared to negative and neutral emotions (McCarthy, 2011; Ruiz, 2008). It is possible that this same type of faster behavior may also be present in driving, and may be due to similar mechanisms connecting positive emotion to human performance.

We conducted some additional analyses that divided the roadway into different sections in order to examine driving performance before, during, and after the billboards were readable. These analyses showed that billboards with negative and positive words were associated with a decrease in immediate driving speed compared to neutral words. That is, the speed of the vehicle slowed during the section of the road adjacent to where the billboard was posted and could be read, suggesting that the drivers' attention was captured by the emotional billboards. Moreover, this slowing effect carried over to sections of the road following the location of the billboard in the positive emotional conditions only. Interestingly, the pattern of effects was reversed for target signs (animal words), such that driving speed increased during the section of the road where the target billboard could be read in the emotional conditions compared to the neutral conditions, and again, these effects lasted longer in the positive emotional conditions. Thus, we observed reciprocity, where positive billboards were associated with decreased speed for a full 200 m following the sign position, but when the sign was a target word requiring a response, the effect was an increase in speed for the full 200 m following the sign position. These findings suggest that positive billboards have both immediate and lingering effects on driving behavior and may actually be more detrimental than the effects of negative billboards.

Drivers were able to maintain appropriate lane position (based on corrective steering wheel activity) when encountering negative and positive words compared to neutral words. However, these steering wheel effects were restricted to roadway positions where the billboards were visible and disappeared after the billboard had been passed. Thus, the steering wheel activity did not linger as long as the mean speed effects. Moreover, the steering effects were reversed during target billboard presentation, where there was more steering wheel activity in the neutral conditions compared to the emotional conditions. Thus, as in the mean driving speed data, we observed a switch in performance between the emotional billboards and the non-emotional target billboards that presumably required additional cognitive control processing associated with decision and response preparations. This pattern of effects may also be associated with the fact that we did not observe an increase in lane deviations.

Using a driving simulator limits the generalization of our results to the real world. However, our simulator approximates the real world experience in that participants must a) do a visual search of the environment for pedestrians, stop signs, and traffic lights, b) brake and respond accordingly, and c) maintain lane position. According to De Waard (1996), our primary measures of driving performance – RMSE lane position and RMSE steering wheel rate – are valid measures that resemble measures used in on-road driving studies. While not a substitute for real driving, various studies have shown that driving simulators have predictive validity (Bédard et al., 2010; Lew et al., 2005; Reed and Green, 1999). Furthermore, our simulation did not include an immersive environment where the visual array surrounds the operator's head, which limits the impact of our findings.

5.1. Conclusions

The relationship between emotion and cognition is complex, but it is widely accepted that human performance is altered when a person is in an emotional state. It is critically important to fully understand the impact of emotion on driving performance because North American roadways are lined with billboard advertisements and messages that contain many varieties of emotional information. Moreover, the distracting effects of emotion may come in other forms such as cell phone or passenger conversations, radio information, and texting information.

Driving is a task that requires a high level of attentional resources in order for the driver to regulate proper speed, maintain effective steering control and lane position, and safely respond to pedestrians, roadway signs, traffic lights, and other relevant sources of information. However, attentional resources are limited in nature and when distraction occurs the operator will often experience deficits in their driving performance. The findings in the present study show that distraction that is emotion-based can seriously modulate attention and decision-making abilities and have adverse impacts on driving behavior for several reasons. Our results demonstrate that emotional distraction can impact driving performance by reorienting attention away from the primary driving task to the emotional content and negatively influence the decision-making process. One implication of our findings is that roadway safety could be improved with a careful consideration for where on the road certain billboard types are placed. For example, it may not be ideal for emotionally arousing billboards to be placed on parts of roadways that require a high degree of visual attention, such as sharp bends, or sites where accident rates are high. The results reported here offer a small window into potential mechanisms for emotional distraction and may inform procedures for driver training, traffic safety issues, and roadway design. Future studies will be necessary to further examine the nature of emotional distraction in other conditions such as under day and night driving conditions, bad weather conditions, as well as to examine the brain-based effects, perhaps revealed by event-related brain potentials and eye tracking.

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Appendix

List of Words* Used in the Experiment

Neutral	Negative	Positive	Animals
BARREL	ABUSE	BEACH	BIRD
CLOCK	CANCER	CASH	CAT
ENGINE	DEVIL	CHEER	COW
FABRIC	FEAR	COMEDY	DOG
FOOT	KILLER	FAME	FISH
ITEM	PRISON	FUN	FROG
LAWN	REJECT	GLORY	LAMB
MONTH	SLAVE	GOLD	LION
PATENT	STRESS	HEART	OWL
PENCIL	THIEF	HUMOR	RABBIT
PHASE	TOXIC	JOKE	SHARK
RAIN	ULCER	JOY	SNAKE
STATUE	VICTIM	KISS	
TABLE	VOMIT	LOVE	
TAXI	WAR	SEX	
THEORY	WHORE	WIN	

*Words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999).

Fig. 1. Distribution of mean speed within each driving condition.

Fig. 2. Distribution of mean steering wheel rate, in the form of root mean square error (RMSE), within each driving condition.

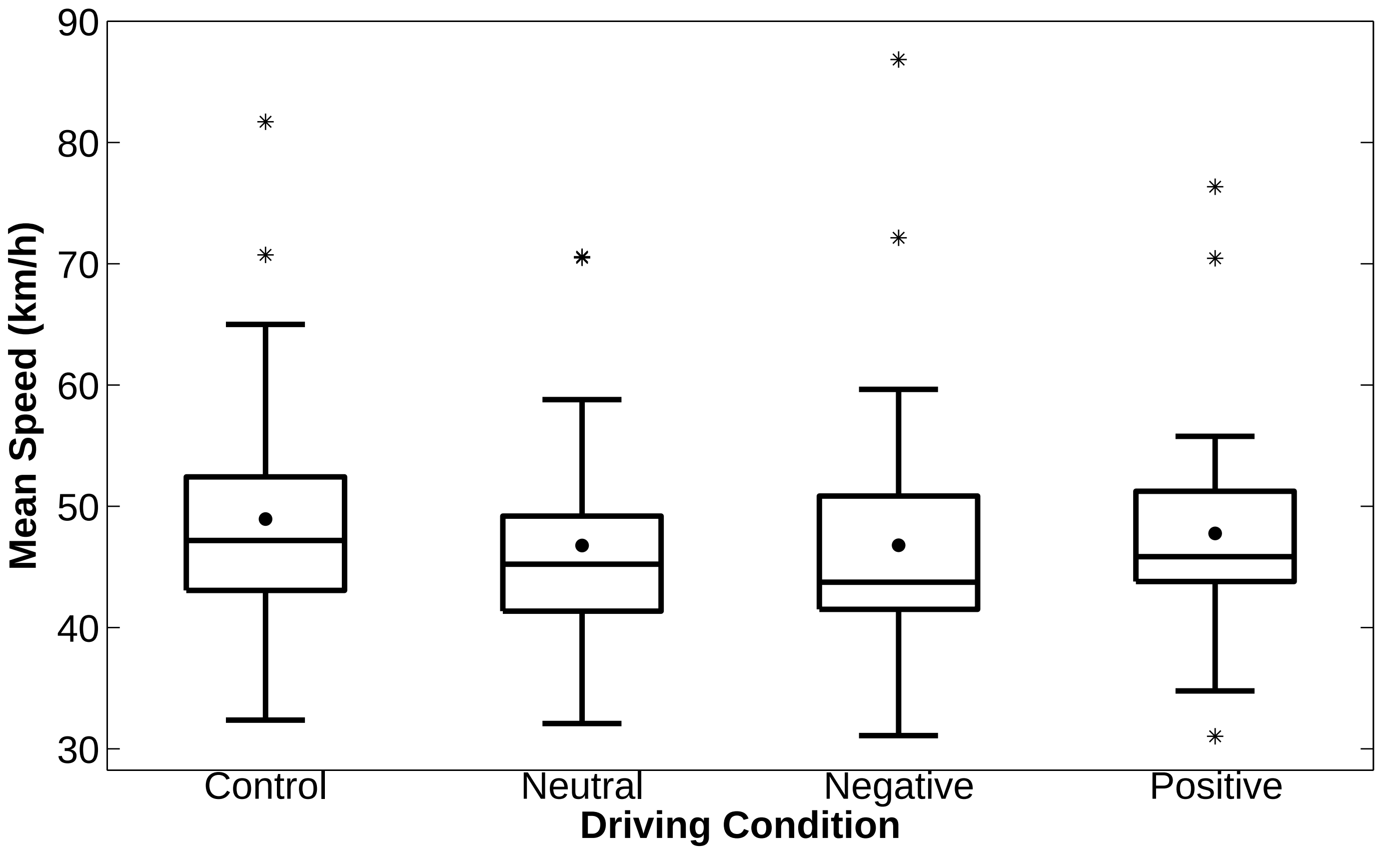
Fig. 3. Distribution of mean steering wheel angle, in the form of root mean square error (RMSE), within each driving condition.

Fig. 4. Distribution of mean lane position, in the form of root mean square error (RMSE), within each driving condition.

Fig. 5. Distribution of mean response times to targets within each driving condition.

Fig. 6. Participant's mean speed within each driving condition, separated by performance averaged over road sections during and after billboard locations (target billboards excluded) (top panel) and road sections during and after target billboards only (bottom panel). Error bars denote standard error of the mean.

Figure 1



90
80
70
60
50
40
30
Mean Speed (km/h)
Control
Neutral
Negative
Positive
Driving Condition

Figure 2

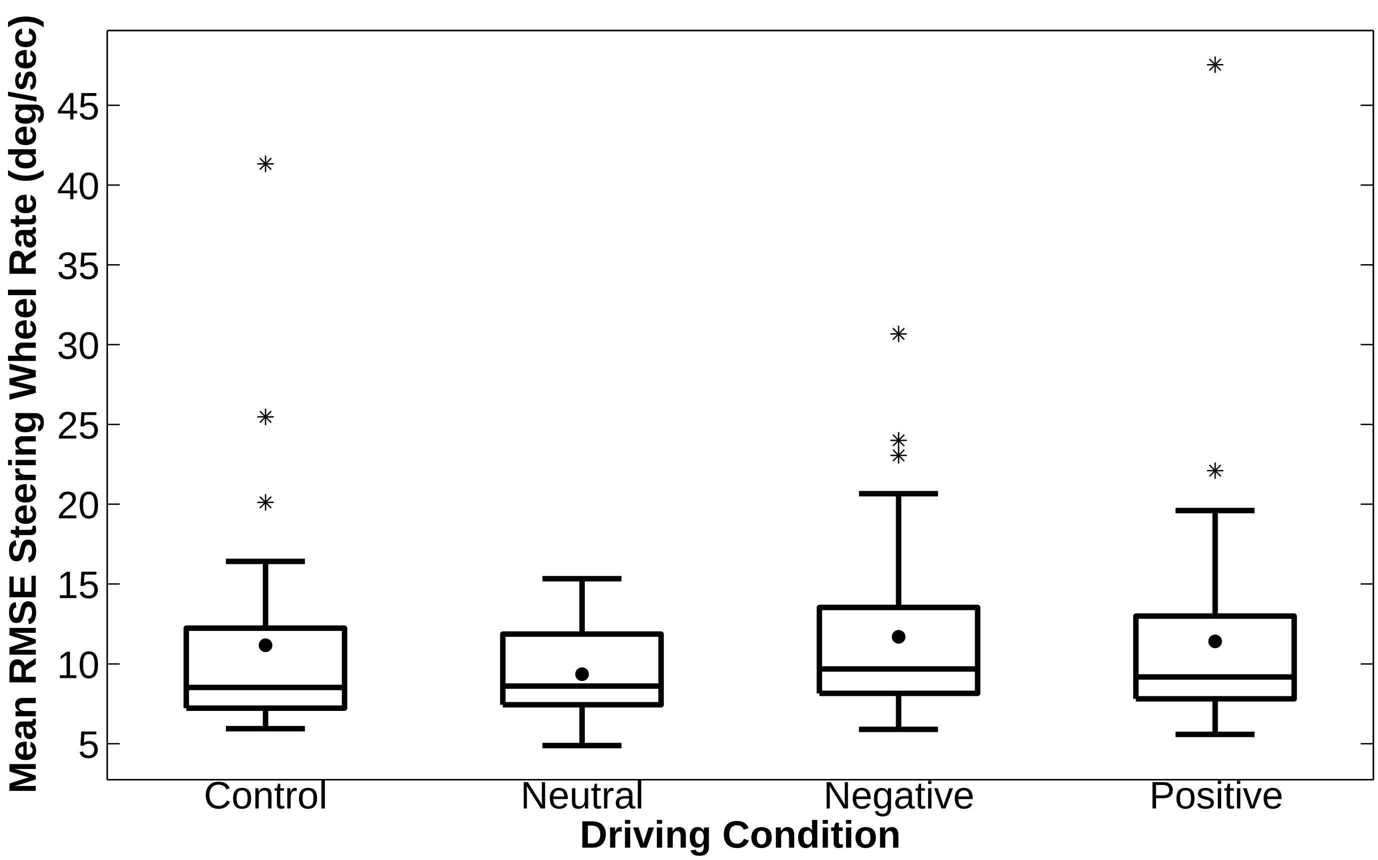

Mean RMSE Steering Wheel Rate (deg/sec)
5
10
15
20
25
30
35
40
45
Control
Neutral
Negative
Positive
Driving Condition

Figure 3

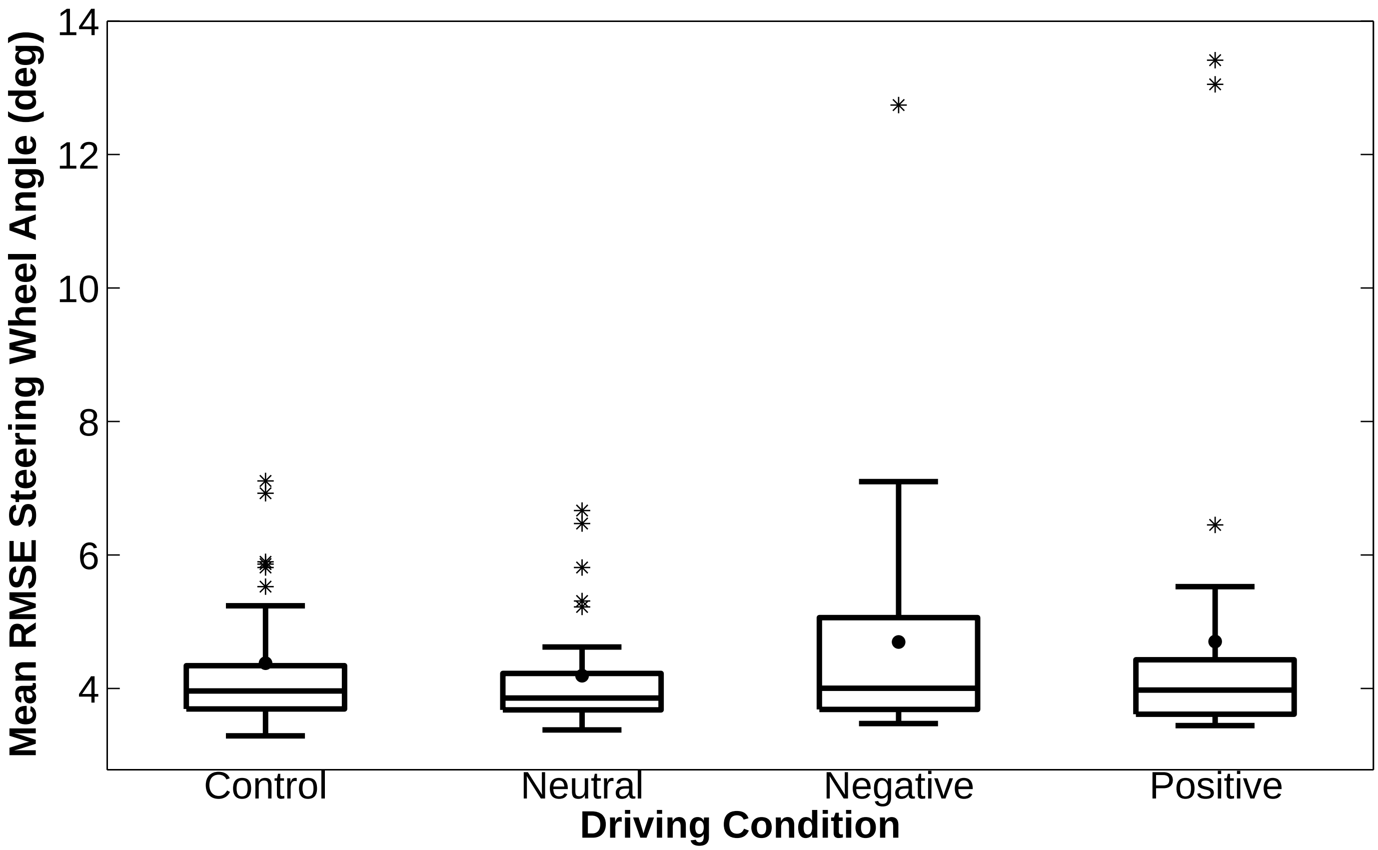
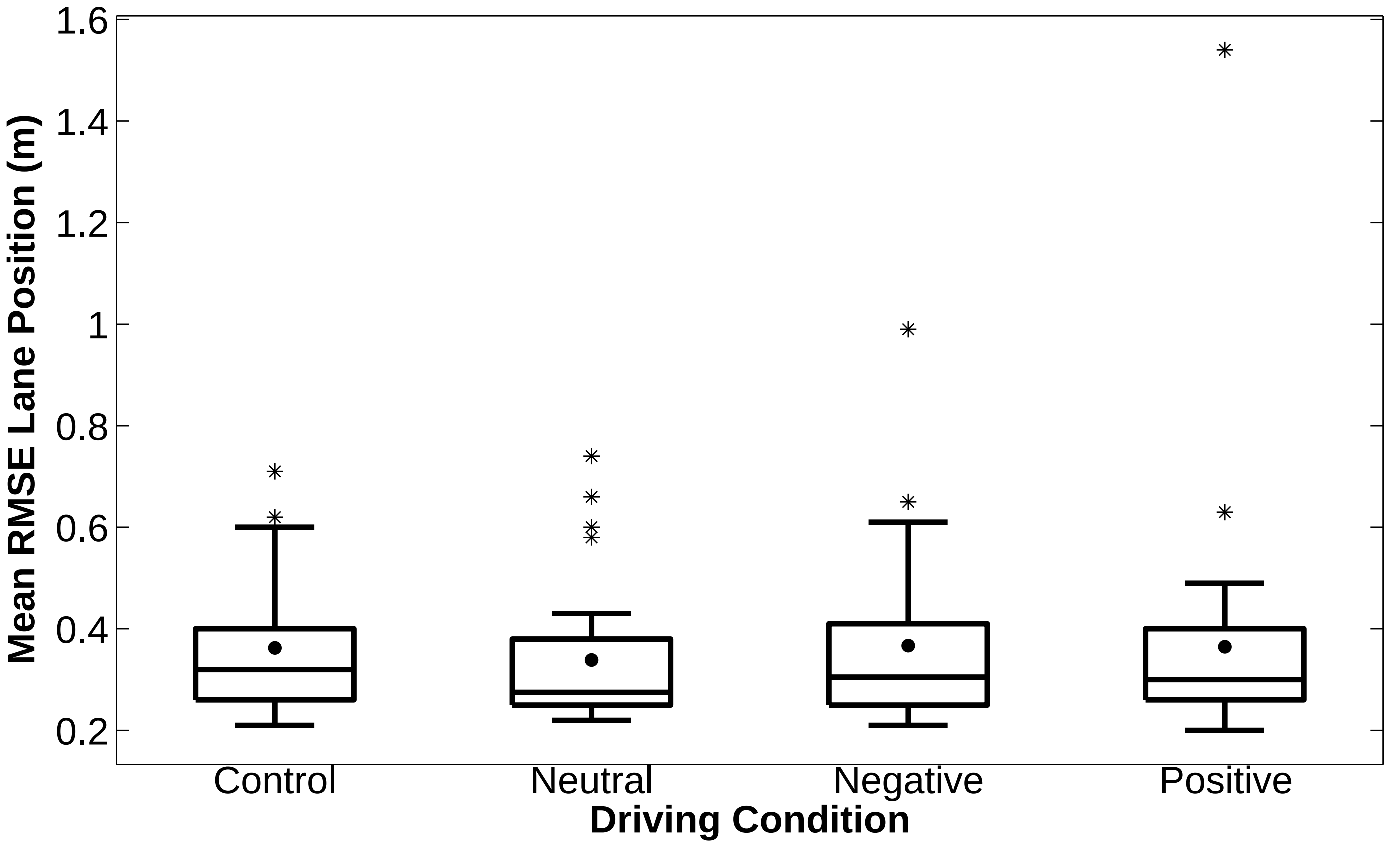
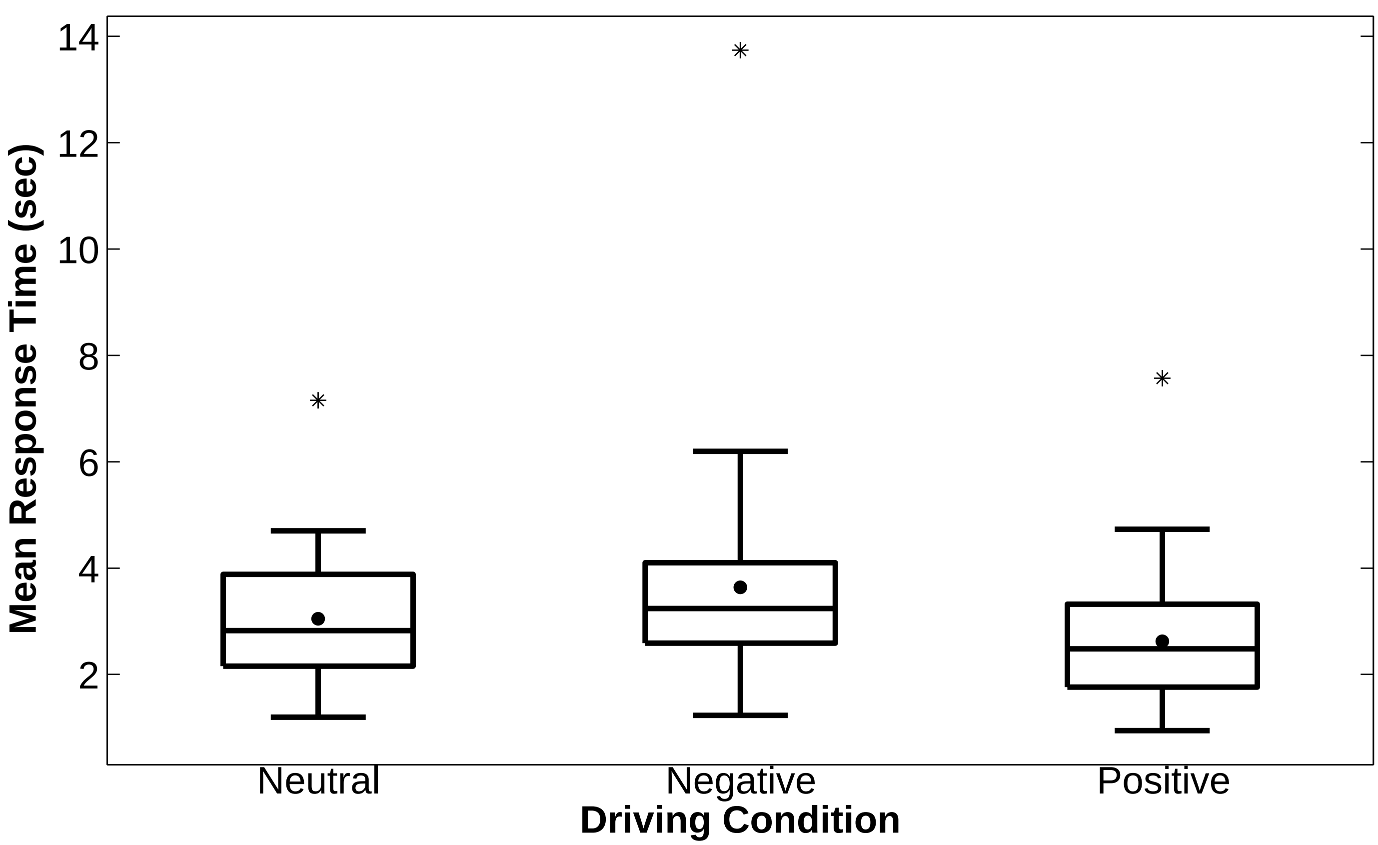

14
12
10
8
6
4
Mean RMSE Steering Wheel Angle (deg)
Control
Neutral
Negative
Positive
Driving Condition

Figure 4



1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
Mean RMSE Lane Position (m)
Control
Neutral
Negative
Positive
Driving Condition

Figure 5



14
12
10
8
6
4
2
Mean Response Time (sec)
Neutral
Negative
Positive
Driving Condition

Figure 6

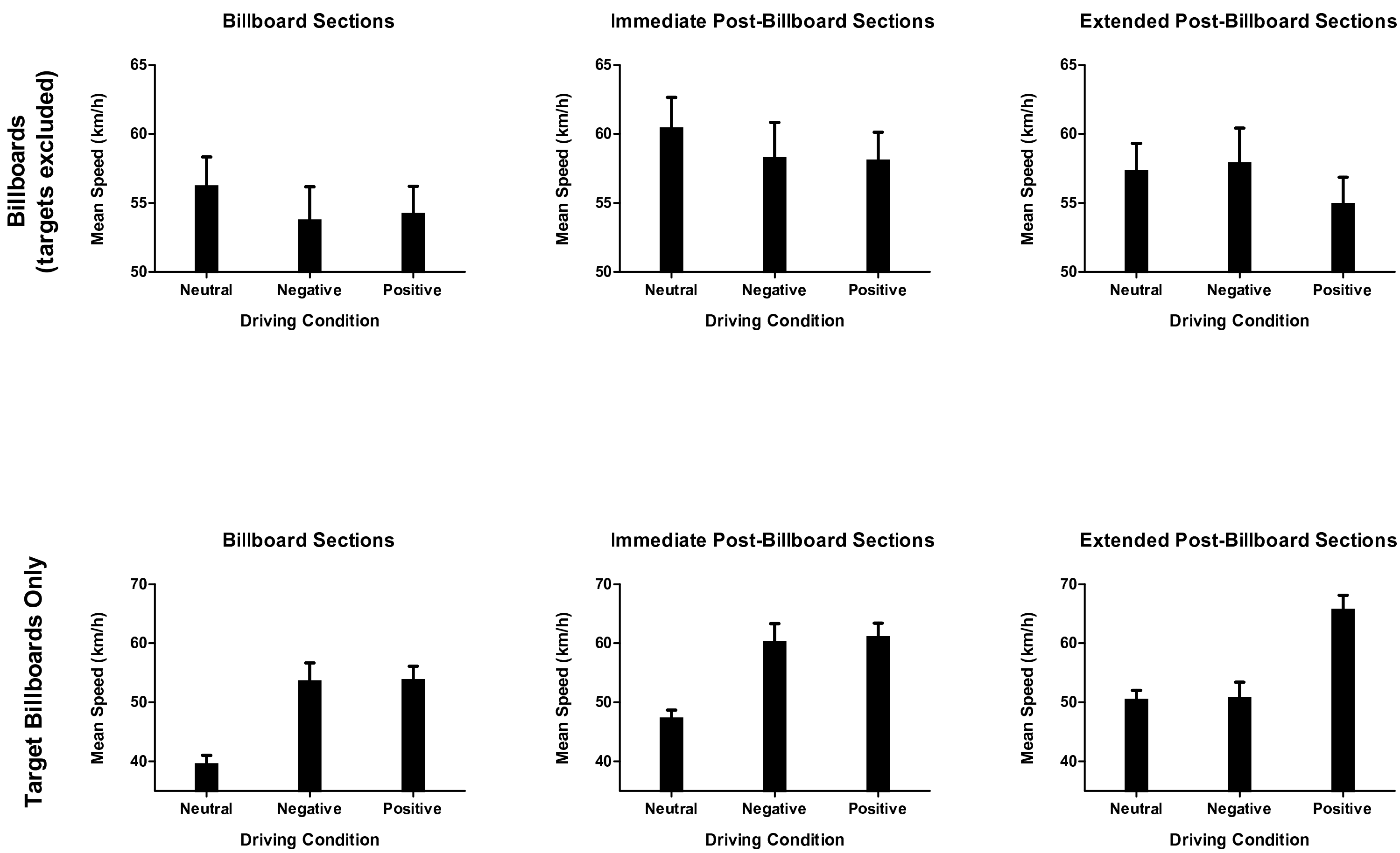

Billboards
(targets excluded)
Target Billboards Only
Billboard Sections
Immediate Post-Billboard Sections
Extended Post-Billboard Sections
Mean Speed (km/h)
Driving Condition
Neutral
Negative
Positive
65
60
55
50
70
40

Table 1

Table 1

Parameters of the Words Used in the Experiment

	Valence	Arousal	Word frequency	Word length
Negative	2.02 (0.31)	6.53 (0.66)	58.8 (113)	5.19 (0.83
Neutral	5.18 (0.10)	3.67 (0.45)	59.3 (52.4)	4.19 (0.91)
Positive	8.15 (0.39)	6.57 (0.73)	59.3 (60.1)	5.13 (0.89)