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Emotion matters: Implications for distracted driving

Michelle Chan [a,*], Anthony Singhal [a,b]

[a] Department of Psychology, University of Alberta, Edmonton, Alberta T6G 2E9, Canada
[b] Neuroscience and Mental Health Institute, University of Alberta, Edmonton, Alberta T6G 2E1, Canada

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ABSTRACT

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. Roadside billboards containing negative and positive emotional content have been shown to influence driving behaviour by modulating attention; however, the impact of emotion-related auditory distraction on driving is relatively unknown. In the present study, we explored the behavioural and event-related potential (ERP) effects elicited by auditorily presented words of different emotional valence during driving (dual-task) and non-driving (single-task) conditions. The results demonstrate that emotion-related auditory distraction can differentially affect driving performance depending on the valence of the emotional content. Negative distractions reduced lateral control and slowed driving speeds compared to positive and neutral distractions. On the other hand, the results revealed an arousal effect on memory and decision-making during driving as performance improved with both negative and positive distractions. Finally, ERPs elicited by the auditory distractions were reduced in amplitude during driving compared to non-driving, revealing a division of cognitive resources under dual-task demands. These findings have important implications for road safety and bring to light the detrimental effects of negative emotional auditory content on driving performance. Furthermore, these findings show that emotional valence and arousal can differentially influence behaviour.

1. Introduction

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. In 2011, it accounted for 10% of all fatal crashes and 17% of injury crashes (NHTSA, 2013). In a recent review by Young and Salmon (2012), secondary task distraction is suggested to be a contributing factor in at least 23% of all accidents.

To distinguish between inattention and distraction, driver distraction has been defined as "a specific type of inattention that occurs when drivers divert their attention from the driv ing task to focus on some other activity instead" (NHTSA, 2013). Thus, distraction involves a triggering event or activity as opposed to inattention due to a cognitive state (e.g., fatigue). Common sources of distraction include cell-phone use, use of in-vehicle information systems, and interactions with passengers. Distraction can also occur when highly salient objects (e.g., a roadside billboard with emotional content) inadvertently draw the attention of drivers (Chan and Singhal, 2013; Megías et al., 2011).

One theoretical account for the cause of distraction is that insufficient attention is devoted to the driving and non-driving related task at the same time. This can occur when the combined demands of driving and the competing activity exceeds the driver's capacity to respond to critical events on the road (Lee et al., 2008). Thus, when drivers are highly engaged with another task, their attention may not be optimal for safe driving due to reallocation of attention to the secondary task.

1.1. Emotional distraction

Emotional stimuli have been widely reported to capture attention more readily than neutral stimuli (Compton, 2003; Vuilleumier, 2005). However, compared to the extensive body of research on secondary task distraction such as cell-phone use, emotion-related distraction is a relatively recent topic in the driver distraction literature. This has important implications as enhanced processing of emotional stimuli may come at the expense of driving performance compared to neutral stimuli.

In Chan and Singhal (2013), roadside billboards containing words of different emotional valence were shown to have differential effects on driving behaviours. The presence of negative words decreased driving speeds and slowed response times compared to positive words. A similar study found that the number of eye fixations and total fixation time elicited by emotional images on billboards were larger than for neutral billboards. In addition, gaze

* Corresponding author. Tel.: +1 780 492 5262.
E-mail address: mc3@ualberta.ca (M. Chan).

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disengagement was later for negative billboards compared to positive and neutral ones (Megías et al., 2011). In an interesting study by Trick et al. (2012), negative images were associated with poorer steering control than positive images. Together, these findings demonstrate that visual stimuli with emotional, particularly negative, content can modulate attention to influence driving performance. It has been suggested that negative stimuli may trigger more attentive, but time-consuming, evaluation than positive stimuli (Pratto and John, 1991); therefore, negative content may lead to worse driving performance.

However, the impact of emotional distraction in other modalities, such as audition, is relatively unknown. This is important as research has shown that in-car listening while driving can be an auditory distracter (Brodsky, 2002; Brodsky and Slor, 2013). Only a few studies have examined the effects of emotional auditory content while driving. In Pêcher et al. (2009), happy music reduced driving speeds and impaired lateral control more than sad and neutral music. In Di Stasi et al. (2010), emotional sounds (e.g., a scream or laugh) decreased alertness in drivers compared to a neutral beep. All these results demonstrate that emotional music and sounds can influence driving performance. However, the impact of emotion-related auditory distraction while driving has yet to be investigated with an electrophysiological approach.

1.2. Event-related potentials

It is widely considered that the human attention system has a limited capacity, and studies show that when two tasks are performed at the same time, there is competition for attentional resources (Bunge et al., 2000; Szameitat et al., 2002). Event-related potentials (ERPs) are well-suited for studying attention-related phenomenon because of their excellent temporal resolution. Extracted from electroencephalography (EEG), ERPs are averaged brain responses that are time-locked to the onset of a stimulus. It is generally considered that the morphology, timing, and topography of ERP components reflect various ongoing cognitive processes, including those related to attention and working memory (Luck, 2005).

In Strayer and Drews (2007), the amplitude of the P300, an ERP known to reflect attention allocation, was reduced in response to the onset of participants' brake response to a pace car's brake lights when conversing on a cell-phone (dual-task) compared to driving alone (single-task). Memory performance on objects in the driving scene was also worse in dual-task conditions, suggesting a diversion of attention from driving to the cell-phone conversation. In a similar study using functional magnetic resonance imaging (fMRI), concurrent performance of a sentence listening task on driving was shown to decrease brain activation associated with the driving task, namely in parietal areas, which has been implicated in the allocation of visual spatial attention (Just et al., 2008). At the same time, driving performance was impaired compared to driving alone. These findings provide evidence of driver distraction caused by dual-task interference, in which a secondary task hinders driving behaviour by competing for attentional resources. In Wester et al. (2008), ERPs related to an auditory oddball task were reduced in amplitude during driving compared to non-driving conditions, indicating that attention was allocated to maintain focus on the driving task at the cost of processing the secondary stimuli. Taken together, these results demonstrate that multi-tasking during driving can increase cognitive workload and lead to competition for limited neural resources.

1.3. Research objectives

In the present study, we sought to examine the nature of distraction due to emotion by measuring the behavioural and electrophysiological effects elicited by auditorily presented words of different emotional valence (neutral, negative, and positive). The words were presented alone (single-task) and while participants operated a driving simulator (dual-task).

There were seven conditions in total: one control condition, where participants drove with no auditory distraction; three single-task conditions, where they listened to: (1) neutral, (2) negative, and (3) positive words; and three dual-task conditions, where they drove and simultaneously listened to: (1) neutral, (2) negative, and (3) positive words. At the same time, decision-making was assessed by having participants respond to target words (animal names) presented in the context of the three types of words. At the end of the study, participants were given a surprise free recall test in which they were asked to recall as many as words as possible from all conditions.

Word stimuli were used in order to more directly compare the findings in this study with those in Chan and Singhal (2013). Our main objective was to determine whether emotion-related auditory distraction would produce similar driving behaviours as has been shown with visual distraction, where driving performance and response times were shown to be differentially affected by the emotional valence of words on roadside billboards (Chan and Singhal, 2013). Our secondary objective was to use ERPs elicited by the auditory distraction to assess the allocation of neural resources under single (non-driving) and dual-task (driving) conditions. To that end, we collected behavioural and ERP data while participants drove a simulator and concurrently listened to words of different emotional valence. We hypothesize that emotion-related auditory distraction will have differential effects on driving behaviours and memory depending on the emotional valence of the words; specifically we predict that (1) negative words will have a higher influence on driving performance than positive and neutral words due to greater recruitment of attentional resources, and (2) more negative words will be recalled than positive and neutral words. We also hypothesize that ERPs elicited by the auditory words will be reduced in amplitude under dual-task compared to single-task conditions, presumably due to a division of neural resources between the driving task and processing of the distracting stimuli.

2. Methods

2.1. Participants

25 participants (13 males; $M = 21.1$, $SD = 3.35$, range 18–30 yrs) from the University of Alberta were recruited via advertisements placed on campus. All were in the age range of 18 to 30 years old and had normal to corrected-to-normal vision. Each received $20 as an honorarium.

2.2. Stimuli and apparatus

120 words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999). As detailed by Bradley and Lang (1999), each word has an assigned valence value on a scale from 1 ("very negative") to 9 ("very positive"), and an arousal value from 1 ("not arousing") to 9 ("highly arousing"). Of these words, 40 were neutral, 40 were negative, and 40 were positive. All words were matched for word frequency. Emotional words were matched for high arousal, with negative words being low in valence and positive words being high in valence. In addition, 30 animal words were selected from the University of Toronto categorized word pool (Murdock, 1976), which acted as target words that participants had to respond to. See Table 1 for details on the word parameters and the Appendix A for a list of the words used.

Table 1
Mean and standard deviation ratings for the words used in the experiment.

	Valence	Arousal	Word frequency
Negative[a]	2.24 (0.74)	6.30 (0.69)	49.0 (81.9)
Neutral[a]	5.27 (0.41)	3.53 (0.34)	49.6 (54.9)
Positive[a]	7.91 (0.42)	6.30 (0.72)	48.0 (56.8)
Target (animals)[b]	4.95 (1.43)	4.49 (1.11)	9.27 (11.14)

[a] Ratings were taken from the Affective Norms for English Words database (Bradley and Lang, 1999).
[b] Ratings were taken from Warriner et al. (2013).

All words were spoken by a male voice and presented through two speakers located on either side of the monitor. They were presented in a randomized manner with an interstimulus interval ranging 2500–7500 ms (volume: 70–85 dB SPL).

Participants drove a STISIM Drive™ (Systems Technology, Inc.) fixed-based driving simulator modeled as a small automatic transmission passenger vehicle. The simulator consisted of a steering wheel, gas/brake pedals, and a 22″ widescreen computer monitor providing a projected field-of-view of approximately 60° horizontal and 40° vertical. The display included a rear-view mirror and speedometer.

2.3. Design and procedure

The driving scenario was 3.6-km long and simulated a two-lane, bidirectional highway in a rural setting. The road consisted of straight roads and slight bends. Daytime and good weather conditions were adopted to provide good visibility. In addition, buildings, trees, and oncoming traffic were included to enhance realism.

Participants were first familiarized with the simulator by completing a practice run of the driving scenario. They were instructed to drive their vehicle in the center of their lane and maintain a speed of 40–80 km/h. The experimenter monitored the practice run to ensure participants were driving to criterion.

Following the practice, a repeated-measures design was employed in which seven conditions (one control and six experimental) were performed in 1 h. The order of all seven conditions was counterbalanced across participants.

The single-task conditions were: (1) listening-neutral, (2) listening-negative, and (3) listening-positive. The dual-task conditions were: (1) driving-neutral, (2) driving-negative, and (3) driving-positive. In the control condition participants drove with no auditory distraction.

In each experimental condition, participants were auditorily presented with 25 words, of which 20 were neutral, negative, or positive, and five were animal names. Participants were instructed to press a button on a response pad located near their dominant hand as quickly as possible when they heard an animal target word. In the single-task conditions, participants fixated on a dot located in the center of the monitor. In the dual-task conditions, participants operated the driving simulator at the same time.

Upon completion of all conditions, participants were given a surprise free recall test on the words, in which they were instructed to type as many words as they could from memory within 5 min.

2.4. Behavioural measures

Three driving performance measures were collected: speed, lane maintenance (assessed as the root mean square error [RMSE] of the driver's lane position down the center of the road), and steering wheel rate (assessed as the RMSE of how fast the driver is turning the steering wheel while doing steering manuveurs) (Rosenthal, 1999). Response times (RTs) and error rates for the animal target words were also collected. Error rates included false positives (i.e., responses to a non-target word) and misses (i.e., failure to respond to the target at all). Proportion of words recalled was defined as the mean number of correct words recalled of each word type, divided by the total number of words presented of each type.

2.5. EEG recording and pre-processing

Recording took place in a sound-attenuated and electrically shielded room. The EEG was recorded with 256 electrodes referred to the vertex electrode (Cz) using a Geodesic Sensor Net (Electrical Geodesics Inc., Eugene, OR). Impedances were kept below 50 kΩ. After re-referencing to a common average reference, the data was filtered with a 50 Hz low-pass and a 1 Hz high-pass filter before being segmented into 1200 ms epochs, time-locked to the auditory stimuli (200 ms pre-stimulus and 1000 ms post-stimulus). Eye blinks and eye movements were corrected for using an ocular artifact algorithm (Gratton et al., 1983). Grand averages of the ERPs were calculated for all participants from artifact-free EEG segments from each condition.

3. Results

All effects were considered statistically significant based on the alpha level of 0.05. Greenhouse-Geisser corrections were applied to account for violations of sphericity.

3.1. Driving task

All of the driving performance data were analysed with separate one-way repeated measures analysis of variance (ANOVA) with four levels (driving condition: control, neutral, negative, positive).

Results revealed a significant main effect of driving condition on mean driving speed, $F(3,72) = 3.36$, $p < 0.05$, $\eta_p^2 = 0.123$, as shown in Fig. 1a. Planned contrasts indicated that mean speed was slower in the negative words condition compared to the control ($p < 0.05$), neutral words ($p < 0.05$), and positive words ($p < 0.05$) conditions.

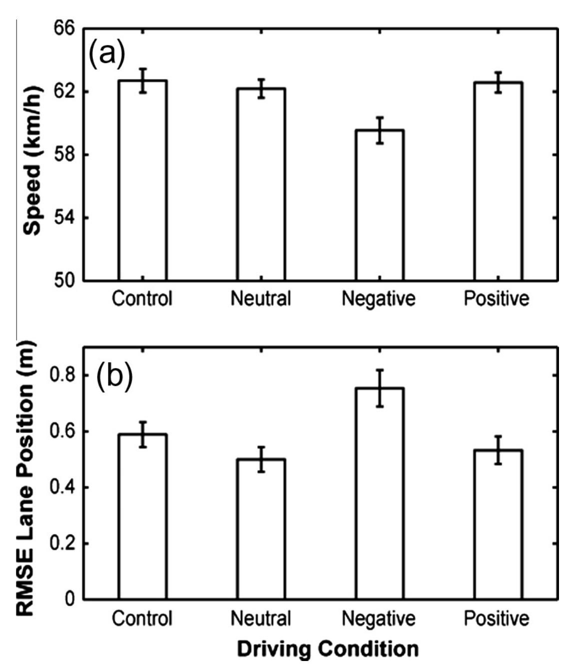

Fig. 1. Participants' mean driving performance, measuring (a) speed and (b) root mean square error (RMSE) lane position. Error bars denote within-subject standard error of the mean.

The analysis also revealed a significant main effect of driving condition on RMSE lane position, $F(3,72) = 3.62$, $p < 0.05$, $\eta_p^2 = 0.131$, as shown in Fig. 1b. Planned contrasts indicated that RMSE was higher in the negative words condition compared to the control ($p < 0.05$), neutral words ($p < 0.05$), and positive words ($p < 0.05$) conditions.

RMSE steering wheel rates did not differ significantly between driving conditions, $F(3, 72) = 1.42$, $p = 0.252$, $\eta_p^2 = 0.056$.

3.2. Target RT

The RT and error rate data were analysed with separate 2 (task condition: single-task, dual-task) × 3 (driving condition: neutral, negative, positive) repeated measures ANOVA. Mean RTs and mean error rates for the animal target words are shown in Table 2.

Error rates did not differ significantly between task condition, $F(1,24) = 1.65$, $p = 0.211$, $\eta_p^2 = 0.064$, and driving condition, $F(2,48) = 0.775$, $p = 0.447$, $\eta_p^2 = 0.031$. However, there was a significant main effect of driving condition on mean RTs, $F(2,48) = 4.46$, $p < 0.05$, $\eta_p^2 = 0.157$, as shown in Fig. 2a. Planned contrasts revealed that mean RTs to targets were faster for targets embedded in the positive words condition compared to the neutral words condition ($p < 0.05$).

Table 2
Mean response times (RTs) and mean error rates for the animal target words, with standard errors.

Task condition	Driving condition that targets are in	Mean RT (ms)	Mean error (%)
Single-task	Neutral	1573 (82.0)	8.00 (2.58)
	Negative	1513 (63.5)	9.60 (3.67)
	Positive	1460 (63.7)	7.20 (1.96)
Dual-task	Neutral	1503 (80.5)	11.2 (3.66)
	Negative	1414 (48.0)	15.2 (5.33)
	Positive	1361 (49.5)	9.60 (2.61)

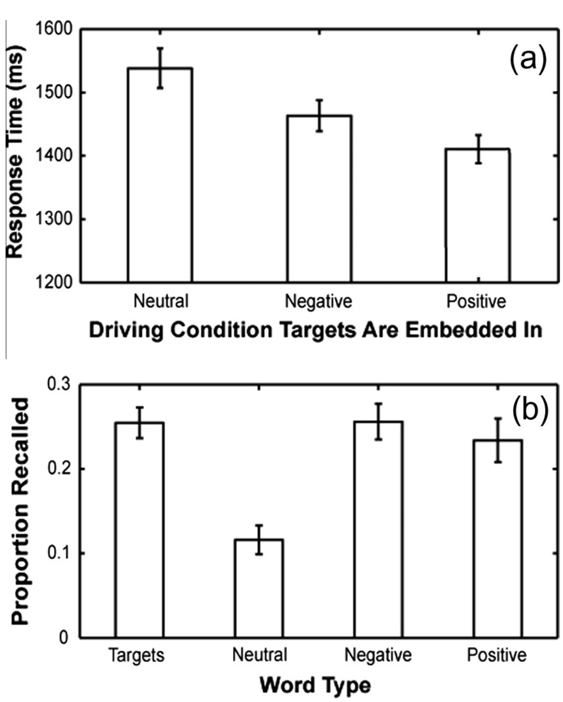

Fig. 2. Participants' (a) mean target response times and (b) mean proportion of each word type recalled across conditions. Error bars denote within-subject standard error of the mean.

3.3. Memory recall

The recall data were analysed with a 2 (task condition: single-task, dual-task) × 4 (word type: target, neutral, negative, positive) repeated measures ANOVA.

The proportion of words recalled did not differ significantly between task condition, $F(1,24) = 1.28$, $p = 0.270$, $\eta_p^2 = 0.050$. However, there was a significant main effect of word type, $F(3,72) = 15.82$, $p < 0.001$, $\eta_p^2 = 0.397$. Planned contrasts revealed that recall was higher for negative words compared to neutral words ($p < 0.001$), and higher for positive words compared to neutral words ($p < 0.01$). Recall of target and emotional words did not differ significantly from each other ($p = 0.710$). As there was no effect of task condition on recall, we collapsed the mean proportion of words recalled across single- and dual-task conditions in Fig. 2b.

Recall for target words as a function of driving condition was also analysed with a 2 (task condition: single-task, dual-task) × 3 (driving condition: neutral, negative, positive) repeated measures ANOVA. There were no significant effects.

3.4. Event-related potentials

The negative slow wave (NSW) was quantified as the most negative-going ERP in the range 430–995 ms at electrodes Fz and Cz. The ERP component was scored by determining the mean peak voltage within the analysed time window. 2 (task condition: single-task, dual-task) × 3 (word type: neutral, negative, positive) repeated measures ANOVA was performed on the amplitude at each electrode site separately. Mean amplitudes of the NSW to the auditory words in single and dual-task conditions are shown in Table 3.

Table 3
Mean amplitudes (in μv, with standard errors) of the negative slow wave to the auditory words in single and dual-task conditions.

Electrode	Condition	Word type			Total mean
		Neutral	Negative	Positive	
Fz	Single-task	−4.22 (0.61)	−2.84 (0.77)	−1.81 (0.80)	−2.96
	Dual-task	−1.27 (0.70)	−0.56 (0.62)	−2.12 (0.74)	−1.32
Cz	Single-task	−3.33 (0.63)	−1.60 (0.68)	−1.35 (0.63)	−2.09
	Dual-task	−2.39 (0.47)	0.06 (0.56)	−0.73 (0.49)	−1.02
	Total mean	−2.80	−1.24	−1.50	

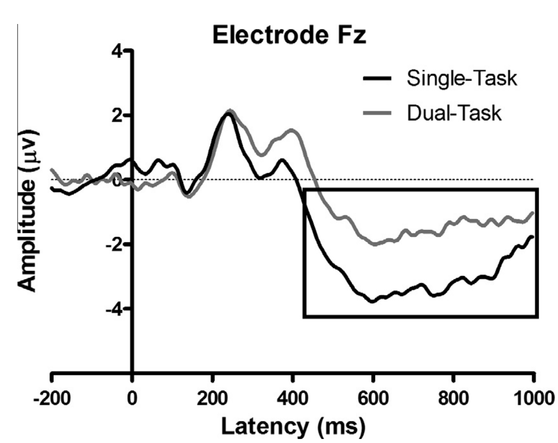

Fig. 3. Grand average ERP waveforms at Fz to the auditory words heard in concurrent with a driving task (dual-task) and alone (single-task). Negative slow wave amplitudes were reduced in dual-task compared to single-task conditions.

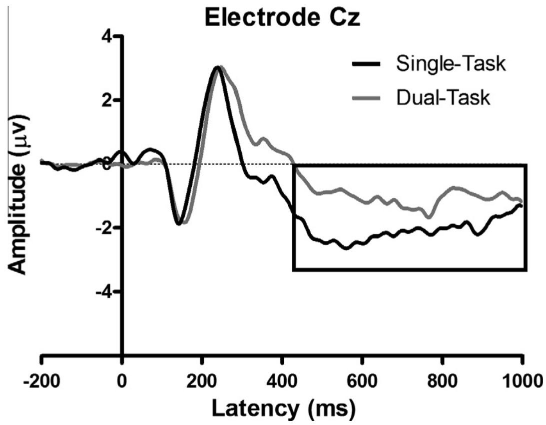

Fig. 4. Grand average ERP waveforms at Cz to the auditory words heard in concurrent with a driving task (dual-task) and alone (single-task). Negative slow wave amplitudes were reduced in dual-task compared to single-task conditions.

Results revealed a significant main effect of task condition on NSW amplitudes at Fz, $F(1,24) = 9.24$, $p < 0.001$, $\eta^2_p = 0.278$, as shown in Fig. 3. Planned contrasts indicated that amplitudes were smaller in dual-task compared to single-task conditions ($p < 0.05$).

A significant main effect of task condition on NSW amplitudes was also revealed at Cz, $F(1,24) = 4.64$, $p = <0.05$, $\eta^2_p = 0.162$, as shown in Fig. 4. Planned contrasts indicated that amplitudes were smaller in dual-task compared to single-task conditions ($p < 0.05$). In addition, there was a significant main effect of word type on NSW amplitudes at Cz, $F(2,48) = 12.2$, $p < 0.001$, $\eta^2_p = 0.338$. Planned contrasts revealed that amplitudes were smaller for negative than neutral words ($p < 0.001$) and smaller for positive than neutral words ($p < 0.001$).

4. Discussion

The present study sought to expand upon the few studies that have examined the impact of emotion-related distraction on driving performance. Specifically, behavioural and electrophysiological effects elicited by auditory words of different emotional valence were examined under non-driving (single-task) and driving (dual-task) conditions. Results showed that driving speeds were slower and lateral control was reduced in the presence of negative words compared to positive and neutral words. RTs to targets were faster within the context of positive than neutral words, and participants recalled more emotional than neutral words. Finally, ERP amplitudes in response to the auditory stimuli were reduced under dual-task compared to single-task conditions. These findings suggest that auditory distraction during driving can increase cognitive workload and that negative emotional auditory content may impact one's ability to drive safely. Furthermore, we demonstrate that emotional valence and arousal can differentially affect behaviour.

4.1. Effects of emotional distraction on driving behaviours

Our main objective was to determine whether auditory distraction of different emotional valence would produce similar driving behaviours as has been previously shown with visual word distraction (Chan and Singhal, 2013). The results support our earlier work, and extend them to emotion-related distraction within the auditory modality.

First, driving performance was found to be differentially affected by the emotional valence of the auditory content. Negative words reduced driving speeds and impaired lateral control compared to positive words, suggesting that the two types of valence modulated performance in different ways. Similar results were found in Trick et al. (2012), where negative images were associated with poorer lane control than positive images. It has been proposed that because negative stimuli facilitate adaptive behaviour and promote survival, there is a stronger attention bias towards these stimuli (Pratto and John, 1991). In light of this, negative distractions may have recruited more attentional resources than positive and neutral distractions, resulting in poorer driving performance. On the other hand, our findings indicate that positive words were associated with safer driving behaviours and faster responses to targets. It has been suggested that positive states may have an effect of broadening attention (known as the "broaden-and-build" effect) (Fredrickson and Branigan, 2005). This may have led to better driving behaviours, as opposed to driving with a narrower field of vision.

Second, memory performance was found to be higher for emotional words compared to neutral words. This finding suggests that attention was selectively prioritized to emotional information, despite the fact that participants were not given explicit instruction to attend to those words. The relationship between attention and memory has been widely established (Chun and Turk-Browne, 2007; Singhal and Fowler, 2004). It is possible that attention triggers neural-networks in the prefrontal cortex to fire more frequently to keep information in working memory. Persistent firing intensifies the information and increases the likelihood that it will be encoded in short-term memory (Wang et al., 2011). Because memory has a limited capacity, attentional resources are allocated between competing stimuli to determine which information is encoded. It has also been suggested that emotional stimuli often have priority in attention allocation because they are motivationally relevant and adaptive, i.e., they activate the appetitive and defensive system to facilitate approach and avoidant behaviours, respectively. For instance, when facing an aversive stimulus, a fast response may be necessary for escape, and an appetitive stimulus may facilitate ingestive, exploratory, or sexual behaviours (Briggs and Martin, 2008). As neutral words are much lower in arousal than positive or negative words, our recall finding reflects an effect of arousal, rather than valence. One possible explanation for the lack of difference in recall between single- and dual-task conditions is that two forms of attention may be utilized during the driving and recall task. The literature strongly suggests that there are two forms of attention: bottom-up automatic attention and top-down controlled attention (e.g., Armstrong and Singhal, 2011). It is possible that automatic processes that require little executive attention may be associated with the driving task, while controlled processes that rely on executive control (e.g., working memory) may be associated with the encoding and storage of items in memory. This distinction may explain why there was little to no interference between the driving task and memory performance.

Finally, the results showed that RTs to animal target words were faster within the context of positive words compared to neutral words. This converges with Chan and Singhal (2013) and is consistent with several lines of research associating positive states with faster physical performance and decision-making (in the form of RTs) compared to negative and neutral emotions (Feyereisen et al., 1986; Leppänen et al., 2003; McCarthy, 2011; Stenberg et al., 1998). The results also showed that RTs to targets did not significantly differ within the context of positive and negative words, suggesting an effect of arousal, rather than valence (i.e., drivers respond faster to targets when arousal is high). Similar results were found in Trick et al. (2012), where braking RT to hazards were shown to be faster following high arousal images.

Collectively, we were able to show that auditory distraction of different emotional valence can produce similar driving behaviours as has been shown with visual word distraction (Chan and Singhal, 2013). In both modalities, emotional word distraction has priority in attention, with unique effects on driving performance, memory, and decision-making. Our findings also suggest that emotional valence and arousal can differentially influence behaviour: the effect of driving performance appears to be driven by valence, while memory and decision-making appears to be driven by the arousal aspect of emotion.

4.2. ERP effects during driving

The secondary objective of our study was to use ERPs elicited by the auditory distraction to assess the allocation of neural resources under single and dual-task conditions. In cognition, it is likely that sensory information must be committed to short-term working memory before it can be acted on. Our auditory task required participants to manually respond to target words embedded in blocks of neutral, negative, and positive words. To accomplish the task, auditory information must be attended to and then retained in conscious awareness. This engages selective attention processes, along with the transfer of information into working memory, before it can be acted on (Singhal and Fowler, 2004). ERPs related to working memory operations can be used to make inferences about cognitive workload under single- and dual-task demands. Thus, we examined early NSW activity at electrodes located in the frontal and central scalp regions to assess working memory operations likely associated with information encoding, maintenance, and retrieval (Ruchkin et al., 1995).

From a cognitive resource point of view, NSW amplitude can be thought to reflect the amount of available working memory resources allocated to the auditory stimuli. From this perspective, smaller amplitude reflects less processing of the auditory words, presumably due to interference of the primary driving task (Gopher and Donchin, 1986). Our results showed that NSW amplitudes were reduced in dual-task compared to single-task conditions, suggesting that working memory processes toward the auditory stimuli are load-dependent. Reduced processing of the secondary stimuli under dual-task demands is consistent with prior research (Singhal et al., 2002; Singhal and Fowler, 2004; Wester et al., 2008), and suggests that the primary driving task may have shifted cognitive resources away from processing the distracting stimuli. Thus, there is a division of neural resources under dual-task demands.

At Cz, NSW amplitudes were smaller in response to emotional than neutral words, suggesting that cortical processing of emotional words differs from that of neutral words. It has been shown that the arousal response to emotional stimuli can activate a broad network of brain regions to influence perception, memory, and attention (Compton, 2003). The amygdala is part of an extensive network that has been implicated in enhancing the effects of emotion on attention and memory; thus, it is conceivable that this "emotion network" may be involved in processing the emotional words. This distinct NSW modulation to emotional stimuli likely reflects unique emotional processing in the brain.

4.3. Simulation validity

Driving simulators provide a safe environment to assess driving behaviour in risky situations. Factors that affect driving behaviour, such as weather and traffic density, can also be optimally controlled by the researcher. However, the simulator is limited in generalizability to actual driving for the following reasons: (1) The simulator has a limited field-of-view that does not surround the driver, (2) a fixed-based simulator offers no vestibular and proprioceptive information for self-motion perception, and (3) the simulated image has limited resolution. Additionally, there is controversy regarding the extent to which behavioural measures of the simulator resembles actual driving. Despite these limitations, there is ample evidence indicating the relative and predictive validity of driving simulators when considering measures of velocity, lateral control, and RT (Bédard et al., 2010; Kaptein et al., 1996; Lew et al., 2005; Mullen et al., 2011; Wang et al., 2010). Moreover, Reimer and Mehler (2011) has shown that physiological measures (heart rate and skin conductance) recorded in a driving simulator during varied levels of task difficulty can provide valid measures of what to expect in the real world when assessing the impact of cognitive workload.

4.4. Conclusions

In 2011, 10% of all fatal motor vehicle crashes and 17% of all injury crashes involved driver distraction (NHTSA, 2013). Our findings confirm that auditory distraction during driving can increase cognitive workload. This was supported by a division of neural resources, as demonstrated by reduced ERP amplitudes to the distractions under dual-task (driving) compared to single-task (non-driving) demands. We also show that emotion-related auditory distraction can modulate attention to differentially influence driving performance. Specifically, negative distractions reduced lateral control and slowed driving speeds compared to positive and neutral distractions.

These results have important implications for road safety, particularly when considered in conjunction with analogous findings that emotional words on billboards can disrupt driving performance (Chan and Singhal, 2013). First, our findings reinforce the importance of taking into account emotional valence and arousal in driver distraction research as they can differentially influence behaviour. We confirm a valence effect on driving performance as negative and positive emotional words were shown to differentially affect driving speeds and lateral control. On the other hand, we found an arousal effect on memory and decision-making during driving. Second, these results bring to light the detrimental effects of auditory content containing negative emotional words. We suggest the need for risk prevention programs, drivers' training protocols, and road safety interventionists to increase public awareness on these sources of distraction in order to limit their occurrence. Finally, these findings may provide important information for the improvement of speech messages/words from in-car driving support systems.

To better understand the influence of emotional content while driving, future work should be conducted with more realistic emotional stimuli, such as having drivers listen to radio broadcasts with different emotional messages. It would also be useful to vary the complexity of the driving situations (e.g., driving in a busy city compared to a monotonous highway) to examine the influence of emotion under different cognitive loads.

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Appendix A

List of words used in the experiment

Neutral words[a]			
Banner	Column	Kettle	Plant
Barrel	Cottage	Lamp	Square
Basket	Curtains	Locker	Statue
Bench	Elbow	Mantel	Table
Board	Engine	Metal	Taxi
Bus	Fabric	Museum	Tree
Cabinet	Foot	Paper	Umbrella
Chin	Fork	Patent	Utensil
Circle	Headlight	Pencil	Violin
Cloud	Item	Phase	Writer
Negative words[a]			
Abuse	Fight	Misery	Suicide
Abortion	Gun	Murderer	Torture
Aggression	Hostage	Nightmare	Toxic
Agony	Illness	Pain	Trouble
Assassin	Injury	Poverty	Ulcer
Bomb	Insult	Prison	Victim
Cancer	Jealousy	Rape	Violent
Devil	Killer	Slaughter	Vomit
Disaster	Loser	Slave	War
Fear	Massacre	Stress	Whore
Positive words[a]			
Acceptance	Ecstasy	Justice	Profit
Achievement	Enjoyment	Kiss	Progress
Adventure	Fireworks	Laughter	Promotion
Affection	Freedom	Love	Romantic
Ambition	Fun	Lust	Success
Beach	Gift	Miracle	Sunlight
Beauty	Glory	Money	Treasure
Champion	Gold	Passion	Triumph
Desire	Holiday	Perfection	Valentine
Diamond	Joy	Prestige	Victory
Animal words[b]			
Ant	Giraffe	Peacock	
Antelope	Goat	Penguin	
Bear	Horse	Racoon	
Bee	Leopard	Rat	
Camel	Lion	Sheep	
Cat	Llama	Spider	
Chicken	Monkey	Tiger	
Cockroach	Moose	Wasp	
Donkey	Ostrich	Wolf	
Fox	Panther	Zebra	

[a] Words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999).
[b] Words were selected from the University of Toronto categorized word pool (Murdock, 1976).

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