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How fleeting emotions affect hazard perception and steering while driving: The impact of image arousal and valence

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ABSTRACT

Video-billboards and portable video-display devices are becoming increasingly common and the images they project can often be dramatic or provocative. This study investigated the lingering effects of emotion-evoking images on driving as measured in a driving simulator. Images were projected on an in-vehicle display while drivers followed a lead vehicle at a safe distance. To ensure attention to the images drivers were required to indicate whether each image was positive or negative by pressing a button. Occasional braking events (sudden decelerations in the lead vehicle that necessitated braking) occurred either 250 or 500 ms after the button press. In the 250 ms delay condition braking RT was faster after high arousal images (fastest for high arousal positive images); following a 500 ms delay braking RT was *slower* after high arousal images (slowest for high arousal negative images). Responding to all images reduced steering performance (in the period after the image but before the button press) but image valence had an effect on steering as well. Positive images were associated with better steering performance than negative images, especially when they were both low in arousal: a result that supports the broaden-and-build hypothesis of positive emotions and the theory that ambient (wide field/peripheral) vision controls steering performance. We discuss implications for both basic research on attention–emotion and applied research on driving.

1. Introduction

Individuals may experience a variety of transient emotions while driving an automobile: exhilaration as the wheels hug the curves of a winding road; alarm as a semi-trailer drifts into their path; annoyance at a slow moving driver monopolizing the passing lane. Some emotions are inherent in the drive (Mesken et al., 2007) but others arise due to incidental events: energizing or calming music, dramatic or lurid images on billboards or video displays. Research suggests that emotion can have an impact on a wide range of human capacities, from muscle strength to memory (e.g., Schmidt et al., 2009; Anderson et al., 2006, respectively), but when driving, the moment-to-moment effects of emotion may produce immediate and disastrous consequences. Most often these consequences are not the products of road rage but rather those of momentary lapses in attention. Inattention is a factor in the majority of collisions and near-misses (e.g., Neale et al., 2005) and it is important to understand how emotion-evoking stimuli influence the ability to perceive and react to changing conditions on the road. This investigation is of relevance for the driving literature but it also has ramifications for basic research on emotion and attention.

Emotion is thought to involve at least two components (e.g., Colibazzi et al., 2010). One is valence, or how positive or negative the stimulus is. For example, generally a playful puppy is associated with positive valence whereas a snarling dog is associated with negative. The second component is arousal, or how exciting or stimulating the stimulus is. An erupting volcano may induce high arousal whereas a peaceful sunset usually induces lower arousal. Specific emotions are associated with different combinations of arousal and valence. For example, the high arousal positive valence combination is associated with happiness or exhilaration. Low arousal positive valence is associated with peaceful contentment. High arousal negative valence is associated with threat (most commonly fear) and low arousal negative valence is associated with sadness or depression. Though valence and arousal are both important in emotion, evidence suggests they are processed in different areas of the brain (Colibazzi et al., 2010; Nielen et al., 2009). For example, in a functional magnetic resonance imaging study that involved showing participants images of different types, Nielen et al. (2009) found that showing high and low arousal images produced differential activity in the middle temporal gyrus, hippocampus, and ventrolateral prefrontal cortex. When participants were shown negative valence images it elicited activity in

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the lateral prefrontal regions whereas positive images elicited more activity in the middle temporal and orbitofrontal areas.

The effects of emotion have been investigated using a range of paradigms (see Yiend, 2010 for a review). There are studies that show that negative valenced (threat-related) stimuli capture attention. Thus, stimuli such as snakes and guns pop out in visual search (Fox et al., 2007). Negative stimuli not only grab attention but they hold it. This can be advantageous when the subsequent task is to identify a target at the same location (Miyazawa and Iwasaki, 2009) but it can be detrimental when it is important to process other stimuli or other aspects of the stimulus. For example, when participants are presented with a rapid sequence of visual stimuli, recognition of a second target is impaired if the first has negative valence. There is an especially large attentional blink for high arousal negative stimuli (e.g., Kihara and Osaka, 2008; Smith et al., 2006). It also takes longer to disengage attention from negative (high arousal/fear-related) items in change detection tasks (McGlynn et al., 2008). Similarly, there is more Stroop interference for negative words (e.g., Watts et al., 1986) and it takes longer to enumerate negative than neutral valenced words (e.g., Gotoh et al., 2008). In addition to the studies focusing on negative (threatening) stimuli, there are others examining the impact of positive valence. For example, positive emotions may prompt individuals to broaden their focus of attention or devote more attention to the global aspects of the display (Rowe et al., 2007; Fredrickson and Branigan, 2005, respectively). This has sometimes been referred to as the “broaden-and-build” effect.

However, it is notable in these studies that many have confounded valence and arousal, insofar as they often make comparisons between negative high arousal stimuli (threatening stimuli) and neutral or positive stimuli that are lower in arousal. More recently, studies suggest that the ability to capture and hold attention may originate more from arousal than valence (Mathewson et al., 2008). Others suggest that valence and arousal produce interactive effects (e.g., Jefferies et al., 2008). It is becoming increasingly clear that it may be necessary to conduct investigations where there are independent manipulations of arousal and valence in order to understand the effects of emotion on performance.

Many people drive while listening to music (Dibben and Williamson, 2007) and in the driving literature emotion is often studied by exposing drivers to music of different types. Research on the effects of music initially stressed the influence of specific varieties of music on driving style. It began with investigations of the negative impact of aggressive/loud (heavy-metal) music on teen drivers (Arnett, 1991) but it soon became apparent that these effects were not restricted to teens or heavy-metal music. Music tempo is a key factor insofar as faster music is associated with higher arousal (Gomez and Danuser, 2007). With increases in music tempo, individuals drive faster, have more collisions and lane crossings, and run more red lights (Brodsky, 2002). Higher levels of arousal are also associated with increases in music volume though the effects do not appear to be linear. Turner et al. (1996) showed that braking times to red lights were faster when music amplitude was moderate (70 dB, close to the preferred level) as compared to when there was no music or when the music was either softer or louder (60 dB and 80 dB). There is less research on valence but one study compared the effects of happy, sad and neutral music on driving (Pêcher et al., 2009). Results indicated that steering was poorer when drivers were listening to happy music than sad – but this finding is complicated by the fact that drivers also adopted different speeds depending on the type of music.

Although there is a body of research on how music influences driving, there has never been an investigation of the impact of moment-to-moment fluctuations in attention produced by viewing emotion-evoking images while driving. Given the increasing prevalence of smart phones, onboard computers, infotainment systems, and video billboards, this issue is of growing concern. Many of these images are designed to be provocative or dramatic and consequently it is important to discover the impact of viewing stimuli with emotional content on driving. Any image may impair driving performance if a hazard appears at exactly the same time as the driver is looking at the image (and away from the road). However, emotional images may have effects that linger after the images disappear (see Hajcak and Olvet, 2008), and these may contribute to “looked but failed to see” collisions: collisions where drivers gaze sightlessly at the road and run straight into hazards that they are looking at (see also White and Caird, 2010). By manipulating the delay between response to the image and subsequent critical events on the road it becomes possible to investigate the time course of these effects.

In the present study, the effects of emotional arousal and valence were investigated by testing participants in a driving simulator. A variety of images that were either high or low in arousal, and positive or negative in valence, were chosen from the *International Affective Picture system* (Lang et al., 2005). These images were presented on a video display in the driving simulator. To ensure that participants were actually attending to the images, they were required to make a button press response after each, indicating whether the image was positive or negative.

Two aspects of driving performance were measured: hazard response and steering. Hazard response was measured in terms of the time required to brake in reaction to the sudden deceleration of a lead vehicle directly in front of the driver (hazard RT). These sudden decelerations occurred either 250 or 500 ms after the button press to the image was complete. These delays were chosen based on the attentional blink research, in which participants are shown rapid serial visual sequences of target and distractor items and are required to report the identities of the targets at the end of each sequence (e.g., Raymond et al., 1992). The attentional blink studies show that when the first target in a sequence precedes the second by 200–300 ms, there are deficits in the ability to report the identity of the second target, as if the need to attend to the identity of the first target suppressed processing of the second. This deficit is typically not as evident when there is 500 ms or more between the first and second target. Although the methodology for the present study is quite different from that used in the attentional blink research, it seemed reasonable to use these times as a starting points. Steering performance was measured in terms of standard deviation of lateral position (SDLP).

Hazard RT and SDLP are interesting insofar as they may tap different types of vision (see Wickens, 2002). Although it is tempting to think that increased hazard RT and SDLP both measure the same thing (bad driving), the correlation between hazard RT and SDLP is not perfect and there are manipulations that have different effects on these variables (e.g., Horrey et al., 2006; Reed-Jones et al., 2008). These discrepancies can be best understood in terms of the distinction between focal and ambient vision (Leibowitz and Post, 1982). Focal and ambient vision serve different functions and have different neural circuitry (Previc, 1998). Focal vision is important in object recognition and visual search, abilities that are especially important in braking RT: the ability to recognize and respond to hazards in the path of the vehicle. Object recognition requires reasonably good visual acuity and because acuity is best in the fovea, this type of vision is closely tied to eye movements. In contrast, ambient vision is used for postural control and locomotion: capacities more closely related to steering. Because the ambient system does not require as much acuity, it does not rely as much on foveal vision. There is evidence that drivers use peripheral vision to steer (Summala et al., 1998, 1996). Moreover, discrepancies between focal and ambient vision produce dissociations between hazard response and steering. Thus, when drivers wore goggles that decreased their visual acuity to 20/200, their hazard response to obstacles was compromised but their steering was not (Higgins et al., 1998). Conversely, reducing the peripheral field of view impairs steering but leaves hazard response unaffected (Owens and Tyrell, 1999). Wickens (2002) posits that ambient and focal vision tap different attentional resources.

Arousal and valence have never been manipulated independently in a driving study, and the differential effects of these variables have not been assessed separately on hazard response and steering. Nonetheless, it is possible to make predictions. First consider hazard response: the sudden braking maneuver required by the deceleration of a lead vehicle immediately ahead of the driver. Because it involves recognizing the hazard and responding appropriately, this might be thought to involve focal vision. According to the broaden-and-build hypothesis, positive emotions are associated with a broader span of attention than negative. A broader span of attention would not necessarily yield an advantage when the hazard is immediately in front of the vehicle though. Thus, arousal may be more important than valence when the task is to respond to deceleration in a lead vehicle. Arousal is important because it mobilizes resources for immediate action: braking should be faster after high arousal images than low. However, it seems plausible that arousal effects would dissipate quickly, and thus the beneficial effects of arousal should be less pronounced with longer delays between the button press response and the subsequent braking event. This suggests that there should be an Arousal × Delay interaction in hazard detection. The justification for this prediction comes from the attentional blink research. Admittedly, there are important differences between the attentional blink paradigm and the one used in the present study. For one, this study measures the time to required respond to an alarming event (sudden lead vehicle deceleration while driving) rather than accuracy at reporting the identity of a second target in a sequence of digits, letters, or words. Nonetheless, given that the effects of high/arousal negative stimuli in the role of first target seem to dissipate once the delay between the first and second targets is in excess of 300 ms in attentional blink studies (e.g., Kihara and Osaka, 2008), in the present study there is reason to expect that arousal would have stronger effects early (250 ms after the button press) than later on (500 ms after the button press).

Predictions about steering are difficult to make based on the previous research, given that the studies that used music to manipulate emotion produced differences in driving speed (Gomez and Danuser, 2007; Pêcher et al., 2009). Speed in itself may influence steering. The present study may be a cleaner measure of the effects of valence and arousal because steering can be measured before appreciable differences in speed emerge. If negative emotions prompt a narrower focus of attention than positive (e.g., Fredrickson and Branigan, 2005), and reducing the peripheral field impairs steering (van Erp and Padmos, 2003), then there is reason to expect negative images should be associated with higher SDLP. Thus, we predict that arousal may be less important than valence when it comes to steering.

To summarize, these are the two main predictions.

Hypothesis 1. For hazard RT, there will be an Arousal × Delay interaction, with high arousal images producing a larger RT advantage when the braking event occurred 250 ms after the response to the image as compared to when the braking event occurred 500 ms after the response to the image.

Hypothesis 2. For steering performance, there will be a main effect of valence, such that the SDLP will be larger after negative valence pictures than positive.

Fig. 1. An in-vehicle display beside the steering wheel presented the images. Response buttons were located on the steering wheel. Four types of image were displayed (high arousal positive, high arousal negative, low arousal positive, low arousal negative). An example of a high arousal negative image is presented here.

2. Materials and methods

2.1. Participants

Twenty-six university students ranging in age from 19 to 23 years participated for course credit. All had at least a G2 drivers' license or equivalent. (In Ontario's graduated licensing program, the G2 license is obtained by taking an on-road driving test. It allows individuals to drive on all roads without supervision. The G2 is usually acquired 8–12 months after drivers obtain their G1. The G1 license prohibits driving on major highways and requires that individuals drive in the presence of a licensed driver.) Two participants were dropped from the study because they developed simulator sickness (there were initially 28 participants).

2.2. Apparatus and stimuli

A fixed base DriveSafety DS-600c driving simulator was used for testing (a Saturn four-door sedan surrounded by five 2.13 m screens that provided a 250° wrap-around virtual environment). The car was equipped with all standard vehicle controls, augmented with audio speakers and vibration transducers and force feedback to simulate the sounds and sensations of driving. The simulations involved five scenic drives through the country on straight two-lane highways (one lane each direction) with a 90 kph posted speed limit. Drivers were required to maintain the speed limit, and if they went outside the 82–100 kph range, the vehicle "labored", providing auditory and haptic feedback. (Participants learned how to maintain the appropriate speed in the training session and had little difficulty holding the required speed over the course of the experiment.) There was a lead car in front of the driver that was programmed to stay 30 m ahead except during braking events, when the lead car decelerated suddenly to a speed of 30 kph (brake lights appeared). Drivers would have to brake to avoid hitting the lead car. Otherwise there was no traffic. Participants were instructed to follow the lead vehicle. (Passing was impossible. The lead car was programmed to stay ahead.) Images and braking events could not occur while the vehicle was "laboring" (traveling outside the designated speed range).

Participants were required to indicate the valence of images that were presented on a 20.3 cm LCD widescreen monitor, mounted on the centre of the dashboard and tilted 45° towards the driver, as shown in Fig. 1. This positioning was chosen because it was similar to that of many in-vehicle displays. For each image, drivers were required to decide whether the image was positive or negative, indicating their response by pressing buttons on the steering wheel. The positive and negative buttons could be easily reached without moving the hands off the wheel. Because the computer that drove the LCD monitor was actually part of the simulator (it used one of the simulator channels) it was possible to program events to occur at closely timed intervals after the button press response.

The images were positive and negative pictures taken from the *International Affective Picture System* (*IAPS*: Lang et al., 2005). Sexual images and violent images were avoided in the interests of ethics because of the danger that some participants might find them offensive. Of the 120 images chosen, 40 were presented before braking events and the other 80 were presented when there was no braking event (no lead vehicle deceleration). Each image was only presented once. The norms from the *IAPS* included average arousal and valence ratings for each picture (1–9 scales, with low numbers indicating low arousal and negative valence). The mean arousal and valence ratings for the 40 images used during the trials where there were subsequent braking events are presented below.

High arousal positive images: *M* arousal = 6.60; *M* valence = 7.47
High arousal negative images: *M* arousal = 6.49; *M* valence = 3.0
Low arousal positive images: *M* arousal = 3.80; *M* valence = 7.58
Low arousal negative images: *M* arousal = 4.23; *M* valence = 3.53

Drivers did five unique drives that were each approximately 15 min long (total drive duration = 75 min; study duration = 2 h). There were many uneventful stretches of highway but once in awhile an image was presented and drivers had to indicate whether the image was positive or negative by making a button press response. There were also periodic braking events. Half of the braking events were preceded by images and half were not. For two-thirds of the images there was no subsequent braking event. Thus, images were not a perfect predictor of braking events because braking events occurred without images and images without braking events. When images and braking events occurred during the same trial, the braking events occurred 250 or 500 ms after the button press response was complete. Across subjects, each image was presented at each delay. The order of presentation for the different types of trials, and different types of image at different delays, were randomized across drives with the restriction that none of the events occurred within the first minute of the drive. There were 24 images per drive and 16 braking events.

2.3. Procedure

Before the study began participants filled out a rating scale to assess their mood (see Jefferies et al., 2008). This scale was used for ethical reasons, in order to screen out individuals who were extremely unhappy. Participants were screened based on their mood so we could avoid showing negative images to individuals who were already depressed. As it turns out, none of the participants had to be screened out based on the mood scale. After the questionnaire was complete, participants were given training. First, they were taught how to do the button press response, indicating whether the image was positive or negative using the buttons on the sides of the steering wheel (left side = positive valence; right side = negative). Once they mastered the button press, participants were given 8 min of training in the simulator. This allowed them to get used to maintaining the required speed and making button presses while driving.

The experimental session involved five different drives (order was counterbalanced across participants) with 2–3 min rest periods between drives. At the end of the experiment, participants were exposed to happy music in order to remove any lingering effects of viewing negative pictures.

3. Results

The following calculations involve repeated measures factorial analyses of variance with partial eta squared used as a measure of effect size. Tukey's *HSD* was applied as needed for post hoc tests. The results are presented in two sections. The first section reports how driving performance changed when drivers were required to make valence judgments about images. This section involves comparing performance in trials where there were images with that when there were none. The second section examines the effects of image arousal and valence on button press RT, braking RT, and SDLP.

3.1. Effects of valence judgment task on driving

In half of the trials there was a button-press image valence judgment before the braking event and in half there was not. To determine the effects of having to make a valence decision, driving performance for trials where there was an image and button press was compared to performance when there was no image and button press. Although images only occurred before half of the braking events, they seemed to serve an alerting function: responses to lead vehicle braking were significantly faster when there were preceding images than when there were not (*M* difference = 105 ms; $F(2,50) = 43.19$, $p < 0.001$, $\eta_p^2 = 0.63$).

The analysis of the steering data was complicated by two considerations. First, there was a danger that braking would produce distortions in steering. As a result, SDLP was only calculated in trials in which there was no braking event. Second, there was a risk that the mechanics of making a manual button press response would inflate SDLP. To prevent this, SDLP was calculated over the 1.5-s period immediately after the presentation of the image but before the button press. Generally, mean button press latencies were in excess of 1.8 s in all conditions, but there were six individuals whose button press RT were less than 1.6 s in one or more conditions. Data from these individuals were dropped from the analysis to ensure that SDLP was only calculated during a period of time when the button press was not underway. Thus, to summarize, SDLP was calculated from the no braking trials, in the 1.5 s immediately after image presentation and before the button press response, in the 20 individuals who had button press RT greater than 1.6 s. Results indicated SDLP after an image was significantly greater than SDLP over a similar duration without a preceding image ($F(1,19) = 42.38$, $p < 0.001$, $\eta_p^2 = 0.68$, *M* difference = 1.18 cm). Overall, when participants were considering their response to the image, their SDLP was greater than it was when they did not have to consider a response. (The effect replicated at $p < 0.001$ when data from all 26 participants were included.)

3.2. The effects of image valence and arousal on performance

3.2.1. Button press RT

In 2/3 of the trials there was an image but no lead vehicle deceleration and thus, there was no need to brake. The following analyses focus on the remaining 1/3 of the trials in which there was lead-vehicle deceleration and a subsequent need to brake (a braking event). To begin, analyses were carried out investigating the effects of image arousal and valence on the button press response to decisions about whether the images were positive or negative. Overall, error rates on these decisions were very low (*M* = 2.82%) and there were no significant effects. However, valence and arousal did have significant effects on response latencies, as shown in Fig. 2. There was a main effect of image valence ($F(1,25) = 6.33$, $p = 0.019$, $\eta_p^2 = 0.20$) and an Arousal × Valence interaction ($F(1,25) = 14.54$, $p = 0.001$, $\eta_p^2 = 0.37$). Specifically, although the difference between

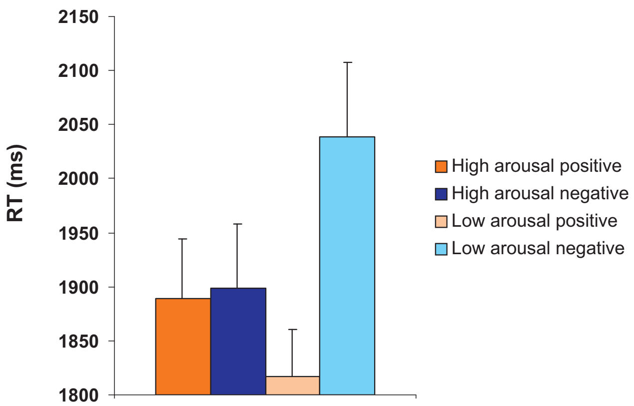

Fig. 2. Response latencies for decision about whether image was positive of negative (button press response) as a function of arousal and valence of the image. Standard error bars are included.

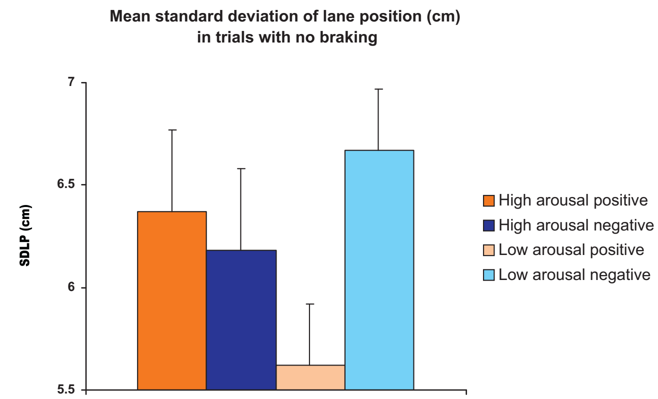

Fig. 4. Average standard deviation of lateral position (SDLP) in centimeters as measured in the 1.5 s after the image but before the button press response in trials with no braking. Standard error bars are included.

latencies for positive and negative images was minimal for high arousal stimuli (M difference = 9 ms, $p > 0.1$), there was a large difference between positive and negative image latencies for low arousal stimuli (M difference = 222 ms; $p = 0.001$). Button-press RT to low arousal positive images was significantly faster than those for the other three types of image ($p < 0.05$). Conversely, RT to low arousal negative images was significantly slower than those for other types of image ($p < 0.05$).

3.2.2. Hazard RT

After the button press response there was a braking event and driving performance was measured as a function of image arousal (low, high), valence (positive, negative) and the delay between the button press and braking event (250 and 500 ms). These analyses revealed that participants were faster to brake when the delay between the button press and braking event was short rather than long (M difference = 19 ms; $F(1,25) = 4.49$, $p = 0.044$, $\eta_p^2 = 0.15$) and as predicted by Hypothesis 1 (see introduction) there was also the Delay × Arousal interaction ($F(1,25) = 5.40$, $p = 0.029$, $\eta_p^2 = 0.18$). An unanticipated Arousal × Valence interaction emerged as well ($F(1,25) = 7.13$, $p = 0.013$, $\eta_p^2 = 0.22$) (see Fig. 3).

To clarify the nature of these effects, performance was analyzed separately for the 250 and 500 ms delays. With a 250 ms delay, participants were significantly *faster* to brake when a high arousal image preceded the braking event rather than a low arousal image (M difference = 23 ms; $F(1,25) = 5.10$, $p = 0.033$, $\eta_p^2 = 0.17$). Analysis of variance revealed no other effects significant at $p < 0.05$.

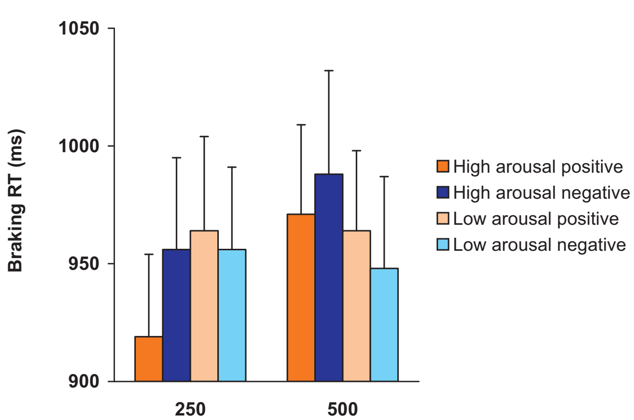

Fig. 3. Response time to brake to sudden deceleration in the lead car as a function of the arousal and valence of the image and the delay between the braking event and button press response to the image. Standard error bars are included.

Nonetheless, high arousal produced a large reduction in braking latencies after positive images (M difference between high and low arousal = 45 ms) but it did not produce a reduction in braking latencies after negative images (M difference = 0 ms).

In contrast, when the braking event was 500 ms after the button press, braking RT were marginally *slower* to high arousal than low arousal stimuli (M difference = 23 ms; $F(1,25) = 3.12$, $p = 0.09$, $\eta_p^2 = 0.11$). There was no effect of valence ($F < 1$) but there was an Arousal × Valence interaction ($F(1,25) = 5.24$, $p = 0.031$, $\eta_p^2 = 0.17$). In this case, arousal had a weaker effect on positive images (M difference high and low arousal = 7 ms) than negative (M difference in high and low arousal = 40 ms), with high arousal associated with increased braking times in each case.

3.2.3. Steering

Steering was measured by SDLP, the standard deviation of the distance between the centre of the vehicle and the centre of the lane, which was measured at a rate of 60 Hz by the simulator. To assess the effects of image arousal and valence on steering, SDLP was measured in trials with no braking event, in the first 1.5 s after image onset. (Only data from the 20 individuals whose button press latencies were in excess of 1.6 s in all conditions were analyzed to prevent SDLP from being influenced by the mechanics of the button press.) Analysis of variance revealed support for the predictions from Hypothesis 2 (see the introduction) insofar as there was a main effect of valence ($F(1,19) = 5.63$, $p = 0.028$, $\eta_p^2 = 0.23$), with higher SDLP for negative images than positive, but there was also a Valence × Arousal interaction ($F(1,19) = 6.87$, $p = 0.017$, $\eta_p^2 = 0.27$) as shown in Fig. 4. Tests of means revealed a significant difference in SDLP between positive and negative trials, but only for the low arousal trials ($p < 0.001$). The effects replicated when data from the six individuals with button press latencies under 1.6 s were included ($p < 0.05$ for both the main effect and interaction).

4. Discussion

Overall this study has implications for both the basic research on emotion–attention and for the more applied research on driving. The results indicate that valence and arousal have interactive effects on both hazard detection and steering, and that these effects vary in their time course. Moreover, the nature of these effects depends on whether the response requires focal attention (used in recognizing and responding to a hazard immediately in front of the vehicle) or ambient attention (used in locomotion and steering).

First, consider the focal attention required in hazard detection. Arousal had the most pronounced effect on braking RT to hazards in front of the vehicle, though the effects varied with the time between the braking event and button press response to the image. With short durations, braking RT were shorter for high arousal stimuli than low, though at longer durations the reverse held. This is consistent with the idea that high arousal events have an immediate influence on response readiness, probably through their activation of the autonomic nervous system. It is also consistent with this effect being very short-lived, such that by the time a few hundred milliseconds had elapsed (the period from 250 ms to 500 ms in this case), the response readiness induced by a negative image had rebounded, leaving the driver in a state of being *less* prepared to respond to the hazard (lead vehicle braking). This interpretation is consistent with numerous effects of reflexive or automatic visual attention in the visual cognition literature. These include the inhibition of return effect in spatial orienting (Klein, 2000), inverse response priming effects of backward masked (subliminal) stimuli (Lleras and Enns, 2004), repetition blindness effects produced by repeated images (Kanwisher, 1987), and rapid adaptation and contrast effects seen in shape perception (Suzuki and Cavanagh, 1998).

The results for the ambient form of attention used in steering were quite different. Here, valence was a more important factor than arousal, though the differences between positive and negative images were largest for low arousal stimuli. In the low arousal conditions, negative images induced significantly poorer steering performance than positive, as measured by SDLP. Furthermore, this valence-related difference in steering could not be accounted for by differences in the difficulty of the valence decision (and thus the time required to make a button press). Although the influences of image valence and arousal on button press RT were qualitatively similar to the influences of these factors on steering, at least in the low arousal condition (see Figs. 2 and 4), it is important to note that button press RT was not correlated with SDLP ($r = -0.10$, $p > 0.2$). Moreover, when the difference in button press RT between positive and negative trials was entered as a covariate in the analysis of SDLP, it had no significant effect ($p > 0.1$) and the effect of valence remained significant ($p = 0.045$, $n = 26$).

If steering performance deteriorates with a narrower field of view, as suggested by the idea that steering involves ambient attention (Wickens, 2002), then the present finding that positive image valence is associated with less steering variability than negative supports the broaden-and-build hypothesis (Fredrickson and Branigan, 2005). However, it is unclear why the effect only emerged for low arousal stimuli. One possibility is that transient arousal serves several functions, improving readiness to respond through general autonomic activation and at the same time narrowing the attentional focus, as has been suggested by studies on the effects of stimulant medications (Mills et al., 2001). These two effects could counteract each other: the effects of reductions in the breadth of the attentional focus may be partially offset by enhanced response readiness. Consequently, the impact of valence may be more visible with low arousal stimuli than high, because the effects of improved response readiness do not obscure the effects of a changing breadth of focus. Thus, for low arousal stimuli, positive valence is associated with better steering and negative valence is associated with worse because of increases and decreases in the breadth of the attentional focus, respectively. The complex interplay between arousal and valence highlights the importance of manipulating these two factors separately when studying the impact of emotion on performance.

This research has a number of shortcomings, some of which were the result of having to balance the conflicting demands of scientific rigor, ethics, and practical considerations. For one, only limited ranges of valence and arousal were explored. Extremely negative or high arousal images were avoided in the interests of ethics. However, it is exactly those types of image that may have the strongest effect on performance. Consequently, the results of this study may underestimate the true effects of valence and arousal on driving.

Second, when finding samples of images from the *IAPS* norms, ideally images that are different in terms of their ratings on one factor (e.g., arousal) should be *identical* in terms of ratings on the other (e.g., valence). That way it would be possible to manipulate one factor while holding the other absolutely constant. For example, it would have been better if we could have found images that were very different in terms of their average arousal ratings, but exactly the same in terms of their average valence ratings. As it turns out, it was surprisingly difficult to assemble sets of images that accomplished this, at least given the other constraints (avoiding upsetting or sexual images, avoiding images that were too similar to one another). As a result, there were differences in ratings between groups of images that should have been identical. For example, the average valence ratings for positive images that were high and low arousal were 7.47 and 7.58, respectively, when ideally the valence ratings for the two types of positive image should have been exactly the same. Worse, the average valence ratings for negative images that were high and low arousal were 3.0 and 3.53 though the valence ratings for these two types of negative image should have been identical. Conversely, for high arousal stimuli that varied in valence, the arousal ratings should have been the same, but there were slight differences. For example, the average arousal ratings for high arousal images with positive and negative valence were 6.60 and 6.49. The situation was even worse for the arousal ratings for low arousal stimuli, where the average arousal ratings were 3.84 and 4.23 of positive and negative pictures. Overall, these differences were generally no more than around 0.5 or so, on a 9 point scale. It is hard to know how much to make of this given that there are individual differences in the response to individual pictures. The norms indicate that the standard deviations in the valence and arousal ratings for the pictures presented before braking events in this study were 1.14–2.7 (Lang et al., 2005). This suggests that the observed discrepancies in valence and arousal between items that should have been in the same category in this study may be minor. Nonetheless, the situation is far from ideal.

Third, there were several problems that stemmed from the need to ensure that participants were actually looking at and thinking about the pictures. To do this, we required participants to make a decision about the valence of the pictures and register their decision by making a button press. There were advantages to the use of the button press device built in to the simulator because we needed to have lead vehicle braking timed to occur 250 or 500 ms after the button press was complete. Such precise timing could best be accomplished with a device that was actually part of the simulator. However, there was a danger that the button press response could interfere with steering. As a result, steering had to be measured over an extremely short duration (before the execution of the button press) and it is surprising that any effects emerged over such a short interval. (At least no speed differences could emerge in that short period of time.) Steering performance was measured in straight sections of the road because there was certainly no way to time events so precisely if there were corners to negotiate. Consequently, this study does not measure the full breadth of the steering response. If a voice-activated relay were used, it would be possible to explore a larger range of steering behaviours.

Further, in this study we ensured that participants were reacting to exactly the same pictures when steering and braking by having button press, braking, and steering measured in the same trial. It is possible that there may have been different results if one group only had to steer after the pictures and another group only had to brake in response to lead vehicle deceleration after viewing the same pictures. Finally, valence and arousal may have different effects depending on the positioning of the hazards. In this study all of the hazards were immediately in front of the vehicle but it is possible that the results would be different if the hazards came from the periphery. Thus, in future research it would be good to manipulate the positioning of hazards. In such investigations it would be especially important to monitor eye movements insofar as valence and arousal may also have an effect on this aspect of performance.

Despite these limitations, overall this study makes a contribution to the research on distraction and driving. There are studies that suggest that roadside advertising, navigational systems and MP3 players divert attention from driving (Young et al., 2009; Horrey et al., 2006; Chisholm et al., 2008, respectively). In fact, even the onboard entertainment systems in other people's vehicles divert drivers' eyes from the hazards on the road (Hatfield and Chamberlain, 2008). However, the present study shows that the effects induced by the emotional content of images linger after the images disappear. Thus, effects are not restricted to situations where the emotional stimuli and hazards occur simultaneously. Emotional effects outlast the stimulus. This conclusion is supported by a recent study that investigated the impact of various types of warning sound when sounds preceded dangerous driving conditions by 500 ms (Di Stasi et al., 2010). This study showed that high arousal emotional sounds were less effective than more neutral sounds in causing drivers to slow down and focus their gaze on relevant areas of the visual scene. Consequently, emotional warning sounds did not reduce the number of collisions whereas more neutral sounds did. The authors suggested that high arousal stimuli might inhibit recruitment of cognitive systems used in strategic response, necessary for choosing the appropriate anticipatory response to upcoming hazards.

However, in the present study there was little need for strategy insofar as there was only one type of hazard (lead vehicle deceleration) and only one relevant response (braking). In this case, exposure to high arousal stimuli produced an initial advantage in hazard detection that reversed within 250 ms, which suggests timing is critical. It is possible that arousal has both high and low level effects: high level insofar as increased arousal may inhibit the strategic processing necessary for choosing the correct type of response when there is a large range of possible hazards and actions, and low level insofar as increased arousal may first facilitate and then detract from readiness to either perceive an expected hazard or carry out the corresponding response. At this point, further research is required to disentangle the effects of valence and arousal on response readiness, the breadth of the attentional focus, and strategic processing while driving.

5. Conclusions

This study shows that emotional content can have different effects depending both on the aspect of emotional experience that is targeted (i.e., arousal versus valence) and the type of driving behaviour under investigation (i.e., hazard detection versus steering). This finding is important for theorists interested in the role of attention in different aspects of the driving task (e.g., Horrey et al., 2006). However, it is also relevant to those in the business of designing technologies that display images to drivers, and should serve as a cautionary tale to anyone attempting to implement a "one size fits all" design solution in the realm of emotional influences in driving.

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