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The influence of driver's mood on car following and glance behaviour: using cognitive load as an intervention.

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Abstract

Driving safety relies on a driver's ability to maintain their attentional focus and that mood is one of the factors which influences this ability. This driving simulator study used mind wandering theory to understand the changes in car following behaviour and driver glance patterns when affected by neutral, happy, sad and angry moods during car following. Two types of cognitive load were used to investigate ways of disengaging drivers from the mind wandering state. The moods were induced via music and mental imagery and assessed via self-reports and physiological measures. The results show that mood valence and arousal have different effects on driving safety, with negative moods resulting in the most dangerous driving, regardless of arousal. The cognitive load, in some cases, disengaged drivers from mood-related mind wandering. However, more detailed research is needed to understand the amount of load necessary for this disengagement in different moods. The importance of using driving-related measures together with glance patterns in mood research was highlighted to overcome ambiguities resulting from conclusions based on single measurements.

Keywords: Sustained attention, Cognitive load, Mood, Emotion, Car following, Time headway

1 Introduction

Driving, similar to other everyday activities such as reading a book, searching for a particular product on a supermarket shelf or listening to a lecture, requires continuous attention regardless of task duration (Langner & Eickhoff, 2013). Fatigue, low motivation or stress can lower the ability to sustain attention for more than a few seconds (Oken, Salinsky, & Elsas, 2006). Sustained attention is

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relevant in both top-down and bottom-up processing (Sarter, Givens, & Bruno, 2001). Top-down processing is driven by previous knowledge which improves the processing of relevant stimuli by filtering them from distractors. In contrast, bottom-up processing is driven by the salience of the available stimuli (Kastner, & Ungerleider, 2000). In the driving environment, both types of processing are equally important in order to maintain safety, thus requiring sustained and active engagement with the surrounding environment in order to predict the actions of other road users. This study aims to evaluate if such sustained attention is affected by driver's mood and if so, how any negative effects might be mitigated.

The induction of both negative and positive moods reportedly leads to increases in subjective and behavioural measures of mind-wandering, as well as task-irrelevant thought (e.g. Seibert & Ellis, 1991; Smallwood, Fitzgerald, Miles, & Phillips, 2009). Christoff, Irving, Fox, Spreng, & Andrews-Hanna (2016) describe mind-wandering as a relatively freely arising mental state or a sequence of mental states in the absence of robust concentration on the task at hand. Previous research has also reported the damaging effects of negative mood-induced mind wandering specifically on driving performance (Dula & Ballard, 2003; Lagarde et al., 2004; Pêcher, Quaireau, Lemercier, & Cellier, 2011) and road hazard identification (Jallais, Gabaude, & Paire-Ficout, 2014). Anger and excitement elicit higher speed and larger deviations in steering wheel angle (Cai, Lin, & Mourant, 2007) whilst sad drivers show impaired hazard perception (Zimasa, Jamson, & Henson, 2017). Although negative moods encourage more mind wandering compared to positive moods (Jonkman, Markus, Franklin, & van Dalfsen, 2017), Pêcher, Lemercier, and Cellier (2009) found that listening to happy music also had a negative impact on drivers' speed and lateral control. In addition, positively primed drivers self-report reckless driving (Taubman - Ben-Ari, 2012) and show increased risky driving in a driving simulator (Eherenfreund-Hager, Taubman–Ben-Ari, Toledo, & Farah, 2017). As well as being classified as either positive or negative (commonly referred to as valence), mood also has an associated arousal state, with arousal being defined as intensity and ranging from very calming, through to highly exciting (Kensinger & Schacter, 2006). Thus a negative mood can be of low arousal (e.g. sadness) or high arousal (e.g. anger) and their effects on information processing differ. For example, Bodenhausen, Sheppard, & Kramer (1994) have demonstrated that whilst induced anger led participants to process information in an automatic mode, sadness encouraged analytic processing of information.

Previous research has therefore shown not only the importance of determining the effects of mood on driving performance, but also highlighted the necessity of establishing ways of reducing the harmful effects of mood-related mind wandering. For example, Berthié et al. (2015) found that mind wandering can be reduced by increasing driving task difficulty, and Morrow and Nolen-Hoeksema (1990) compared the influence of physical and cognitive distraction on neutralising participants' mood in a non-driving environment, finding cognitive distraction to be more effective. Van Dillen and Koole (2007) used cognitive load to disconnect participants from their negative mood and found that by occupying working memory with distracting activities, less capacity remained for the processing of negative thought. Thus, the fewer negative thoughts that are processed, the more an individual's attention is drawn away from the experienced mood and towards a neutral mood. Nijboer, Borst, van Rijn, and Taatgen (2016) found that the effects of cognitive tasks on drivers' performance vary depending on the type of road and traffic density. Drivers are more susceptible to mind wandering on roads with low traffic density which demand less cognitive attention. Therefore, in these situations, mildly demanding activities, such as listening to the radio, have been shown to be beneficial to driving performance (Ünal, de Waard, Epstude, & Steg, 2013). Thus, the present study aims not only to determine the effects of mood-related mind wandering on driving performance where sustained attention is required, but also whether this effect can be mitigated by redirecting driver's thoughts back towards the driving task.

An example of a situation whereby drivers are required to sustain their attention is during car-following as they have to react to speed changes of the lead car. Car following situations are often experienced in every day driving on roads where overtaking is not appropriate. Driving in these situations can be monotonous (Schmidt et al., 2009) and monotonous driving leads to reduced vigilance and consequently, a decline in driving performance (Thiffault & Bergeron, 2003). Thiffault and Bergeron (2003) related decrements in vigilance to impaired information processing and sustained attention. Monotonous driving can also encourage mind wandering (Berthié et al., 2015; Lemercier et al., 2014) and Lemercier et al. (2014) argued that mind wandering is largely caused by monotonous driving, resulting in emotional, ruminative and distracting task-unrelated-thoughts.

One approach to studying sustained attention in the driving environment is to use a standardised car following task (Brookhuis, de Waard, & Mulder, 1994). During this task a driver has to follow a lead car, maintaining a constant distance. The speed of the lead car fluctuates with an amplitude between 15 to 30 seconds, depending on task design (Brookhuis et al., 1994; de Waard, 1996; Rakauskas et al., 2008). Three parameters are measured to assess the influence of experimental manipulations on drivers' attention in the car-following task: coherence, phase shift and modulus (see Section 2.5). These measures have been found to reliably distinguish between drivers affected and not affected by alcohol, antihistamines, conversations and additional load (Brookhuis et al., 1994; Ward, Manser, de Waard, Kuge, & Boer, 2003). Another measure of car following is the choice of time headway (TH), which can also vary depending on road type, driver's age, gender, speed and drivers' goals (Ranney, 1999). Time headway is defined as the time interval separating two vehicles, measured in seconds between the same common external features of both vehicles. Ranney (1999) differentiates between an increase in TH as a result of either situational variations or individual differences. For example, in situations where drivers increase their TH in response to higher mental workload, TH returns to baseline once the workload diminishes. On the other hand, variations in TH due to intrinsic individual differences, such as driver experience, remain relatively stable.

Moreover, Land (2006) states that cognitive processes involved in task completion and action control can be detected by recording eye movements. Longer eye fixations have been attributed to the difficulty in information extraction and processing (Wilson, & Eggemeier, 1991) and related to an increase in workload (O'Donnell, & Eggemier, 1986). In contrast, a wider horizontal spread of fixations has been linked to more efficient road observation (Crundall, Chapman, Phelps, & Underwood, 2003). Crundall et al. (2003) also state that experienced drivers have significantly wider horizontal search spread than novices, which could be one of the reasons for their reduced accident involvement. Therefore, glance behaviour measures can be used to supplement driving performance variables, particularly when workload is manipulated. 'Driving performance' in the present study is used as an umbrella term describing measures directly related to the car following task (correlation, phase shift and modulus) and time headway whilst 'glance measures' includes fixation duration and spread of fixations.

In this study, participants were required to complete the car following task under different mood manipulations and in addition to the metrics described above, glance behaviour measures (fixation duration and spread) were used as an indicator of driver workload and attention. Both mood valence and arousal were manipulated. We firstly hypothesise that the induced moods (apart from neutral) will differentially affect driver performance in a car-following task that requires sustained attention, evidenced by glance and driving performance measures. Secondly, disengaging drivers from the mood-induced mind wandering, using a mildly distracting task, will improve driving performance.

2 Method

2.1 Participants

The participants (26 male and 14 female, mean age 38.48 years, SD 12.29) were recruited using the simulator participant pool as well as personal contacts. The inclusion criteria were driving experience of more than 3 years and an average annual mileage of at least 5000 miles to ensure sufficient driving practice. As a gesture of appreciation, all participants were given £20 on completion of the experiment.

2.2 Material and apparatus

The experiment took place in the University of Leeds Driving Simulator which is based on a 2005 Jaguar S-type vehicle, equipped with fully operational controls, rear view and side mirrors. The vehicle is placed inside a dome attached to a hexapod, with a X-Y table motion platform with eight degrees-of-freedom. A spherical screen projection area displays the road environment at 60 Hz and a resolution of 1920x1200 to the front and 1024x768 in the peripheral and rear views. The forward channels provide a total horizontal field of view of 250˚, the vertical field of view is 45˚ and the field of view of the rear and side mirrors is 42˚.

Eye movements were recorded using a Seeing Machines faceLAB v5 eye-tracker fixed on a front panel in the driving simulator, with an accuracy of ±1° and frequency of 60 Hz. Empatika E4, a wearable wireless multi-sensor device was used to collect physiological measurements during the experiment. Empatika E4 has been used for medical data collection from patients as well as in experimental research and found to be reliable and accurate (Enewoldsen, 2016; Pietilä et al., 2018). Participants were also asked to complete a mood assessment grid (Russell, Weiss, & Mendelsohn, 1989) before the experiment (for the baseline mood measurement), and after the experiment. The grid can distinguish between mood valence and arousal (Kuppens, Tuerlinckx, Russell, & Barrett, 2013).

2.3 Mood induction and cognitive load

Researchers have used a variety of mood induction techniques: imagination, films, stories, music, feedback and combinations of these. Westermann, Stahl, and Hesse (1996) reviewed the effectiveness of these techniques and suggested that combined methods are more effective than using a single mood induction technique. In the present investigation, mood was induced via music and mental imagery (Juslin & Laukka, 2004; Westermann et al., 1996). This study uses emotion to induce different moods as emotion is easier to manipulate in an experimental setting (Rauscher, Shaw, & Ky, 1993). Hu, Tian-Yi, Xie, & Li (2013) state that mood and emotions have a similar effect on drivers' performance, such as higher risk perception and higher self-reported risky driving. The music used to manipulate mood is shown in Table 1 and participants were additionally asked to conjure up mood-appropriate mental imagery whilst listening to the music. The moods were chosen to represent variations of both arousal and valence. The happy mood is deemed as being positive and high arousal, angry as negative and high arousal, sad as negative and low arousal and neutral as positive and low arousal (note that the 'neutral mood' does not reflect the literal meaning of the word 'neutral', but is referred to as such to be consistent with previous research Jallais, Gabaude, & Paire-Ficout, 2014). The particular choice of music was based on previous research investigating the effects of mood on driving performance (Jallais & Gilet, 2010; Kreutz, Ott, Teichmann, Osawa, & Vaitl, 2008; Zimasa et al., 2017), which demonstrated its success in inducing different moods. Two musical fragments for each mood were recorded and played in a loop. To further ensure the effectiveness of the chosen music, the musical fragments were piloted. This also allowed comparison of participant's arousal in different moods using physiological measures and self-reports.

Table 1: Music used for mood induction

Mood	Music
Neutral	1) Chopin Waltz No. 12 (1829) in F minor, Op. 70, No.2
	2) Chopin Waltz No. 11 (1848) in G flat, Op. posth, 70 No. 1
Happy	1) Delibs (1870) Mazurka from Coppelia
	2) Bach (1721) Brandenburg Concerto #2
Sad	1) Chopin (1839) Opus 28,#6, from Preludes, played by Alessandra Ammara, piano
	2) Prokofiev (1938) Russia Under Mongolian Yoke from Alexander Nevsky
Angry	1) Mussorgsky (1867) Night on Bald Mountain, played by symphonic orchestra
	2) Holst (1918) The Planets – Mars, the Bringer of War

Cognitive load, in the form of questions posed throughout the drive, was used to disconnect drivers from mood-induced mind wandering. Two types of cognitive load were presented to the drivers. The first – driving related load (DRL) – consisted of questions deemed relevant to the driving task and hypothesised to improve driving performance more than the second type – non-driving related load (NDRL) – because they direct drivers' attention to the driving environment, thus increasing awareness of traffic related issues. Using the question form of cognitive load was inspired by 'the 20 question task' often used in driving related research (Naujoks, Befelein, Wiedemann, & Neukum, 2017), but adapted to meet the needs of this study by decreasing the task difficulty and increasing relevance to the driving task. The questions used in both tasks can be found in the Appendix and the participants were informed that their answers would not be assessed, but they still had to respond, as this would confirm that they were following the instructions. Driving performance in DRL and NDRL scenarios was compared to a baseline scenario (NONE) where no questions were posed.

2.4 Experimental design and procedure

A (3x4) mixed design was employed with Load as the within-subject factor (3 levels –NONE, NDRL and DRL), and Mood as the between-subject factor (4 levels – Neutral, Happy, Sad and Angry). Thus, within every Mood condition, participants performed three drives: NONE, NDRL and DRL. The order of these drives was counterbalanced (six permutations) (Figure 1).

After completing the consent forms and a standard simulator health and safety briefing, which is used to ensure that participants are aware of experimental procedures, possible risks and what they should do in case of an emergency, participants were asked to complete a mood assessment grid to determine their pre-study mood. The Empatika wristband was placed on the participant's wrist and they were asked to perform a familiarisation (practice) drive with an experimenter present in the simulator. After the practice drive and a short break, the participants remained in the simulator on their own. The baseline drive was then completed (no mood induction or cognitive load). The participants were instructed to drive as they would normally and instructed as follows: "During the car following task, you have to follow the lead vehicle at a distance which you consider to be safest and convenient. The speed of the lead vehicle will fluctuate. You have to try and keep this distance constant and try to do it smoothly, without rapidly braking and accelerating." This baseline drive established participants' normal driving style and highlighted any potential between-group differences.

Following the baseline drive, the baseline physiological measurements were recorded. The participants were asked to close their eyes, sit calmly and relax for four minutes, thinking about something that would keep them calm and as emotionless as possible. After this, the mood induction took place and participants were asked to listen to one of the four musical excerpts listed in Table 1 (at 80dB) and think about events in their life that corresponded to the music. For example, when 'happy' music was played, they were asked to think about something that had happened to them previously and made them happy.

The participants then performed three experimental drives, in the same mood, but each with a different cognitive load. The music was continously played during the three drives to help maintain the mood, but the volume was reduced to about 60dB, the volume of normal conversation. In the NDRL and DRL drives, the questions were posed via the hands-free communication system in the vehicle at a volume of 65dB, so it was not too loud, but could be heard over the music. The volume was measured using SPLnFFT Noise Meter. The participants were instructed to answer every question quickly and instinctively, using one or two words maximum.

Participants were offered short, 2-5 minutes breaks between the drives when they could exit the simulator and sit in the briefing room. Each drive was approximately 15 minutes long. On completion, participants were seated in the room next to the simulator and asked to complete the mood assessment grid again. Finally, participants were debriefed and their right to withdraw their data from the analysis was repeated. The experimental procedure is depicted in Figure 1.

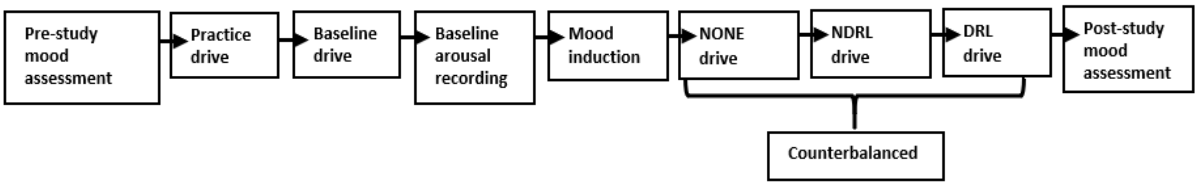

Figure 1: Experimental procedure

2.5 Dependent measures

Self-assessment of mood and the measurement of physiological variables were used to determine changes in subjective and objective measures of mood, as a result of the experimental mood manipulations. The mood assessment grid (Russell et al., 1989) elicited measures of both mood valence and arousal. The participants had to place a cross in the box that represented their mood, using both valence (unpleasant to pleasant from left to right) and arousal (low to high from the bottom to top) on a scale of one to nine. In the example in Figure 2, the resulting mood score would be four on the valence scale and seven on the arousal scale.

The physiological measures of heart rate (HR) and electro dermal activity (EDA) were used as they have been found to correlate with arousal (Borghini, Astolfi, Vecchiato, Mattia, & Babiloni, 2014; Brookhuis & de Waard, 2010; Collet, Salvia, & Petit-Boulanger, 2014; Taylor, 1964). These were continuously measured throughout the whole experiment.

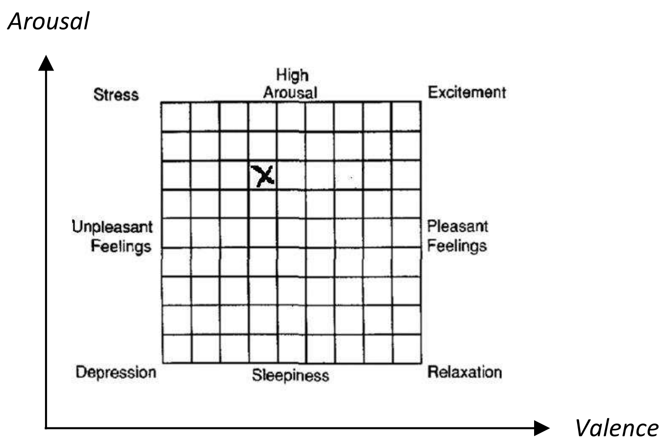

Figure 2: Mood-assessment grid (Russell et al., 1989)

The participant followed a lead car that varied its speed between 50 and 60 mph in an approximate sinusoidal cycle with a frequency of about 0.03 Hz (this means that the lead car reaches its minimum/maximum speed of 50/60 mph every 33.3 seconds and oscillates between them). Several standardised car following metrics were used (Brookhuis et al., 1994). Firstly, coherence was calculated, being a measure of squared correlation between the speeds of the participant's car and the lead car. Its value is similar to R^2, ranging from 0 to 1, with 1 being a perfect match between the two signals. If the correlation is < 0.3, it is concluded that the driver has not engaged in car following and further metrics should not be interpreted. Secondly, modulus was extracted, defined as an amplification factor of the participant's speed with respect to the lead car. Modulus < 1 is interpreted as undershoot, and modulus > 1 is interpreted as an overshoot. Thirdly, phase shift was analysed, representing the delay in a participants' response to the change in speed of the lead car.

In addition, time headway (TH) was analysed with THs longer than 6 seconds being excluded from the analysis, as they are too long to be considered as following behaviour (Vogel, 2002). The proportion of time participants spent in one second intervals (0-1, 1-2, 2-3, 3-4, 4-5, and 5-6[2]) was calculated as a proportion of all time spent following and compared across conditions.

With regards glance patterns, two measures were extracted from the data. First, duration of eye fixations was calculated which has been associated with higher mental workload (Recarte &

2 The times are calculated from 0 to less than 1 (1 not included), from 1 to less than 2 (2 not included), etc.

Nunes, 2000) and a drivers' ability to shift attention in difficult road conditions (Crundall, Underwood, & Chapman, 1998). In addition, the spread of fixations, associated with an increase in cognitive load (Kountouriotis & Merat, 2016), was calculated.

2.6 Data analysis

Driving performance data was missing for two participants in the angry and one participant in the happy mood, due to them overtaking the lead vehicle in the car following scenario. The analysis was therefore performed on 37 participants. In cases where the driving performance data were not collected, the glance measures were still included in the analysis. EDA and HR data from 32 participants was used with eight participants' data having been lost due to a technical fault. The driving related data was processed in Matlab and the data collected from the eye tracker was processed in R.

To ensure that any changes found in driving performance and glance patterns were not due to individual differences, the baseline measures of driving performance, glance and mood data were compared between the four groups of participants; one-way ANOVAs were performed where the data were normally distributed and Kruskal–Wallis tests were used when not. Following this, two-way repeated measures ANOVAs were used to determine main effects and interactions, with the within-subject factor Load and the between-subject factor Mood. For the within-subject effect, Greenhouse-Geisser correction was used if the assumption of sphericity was violated. Planned contrasts were conducted for the between subjects factor of Mood, in preference to post hoc tests, as the latter are ineffective in extracting the effects of central interest from the factorial ANOVA, and are oversensitive to sphericity. Boik (1981) argues that even small deviations from sphericity result in considerable biases in F-tests. Planned contrasts were formulated based on previous findings and to control for Type I errors (Stefan & Mats, 2016). Levine's statistic was used to assess homogeneity of variances. The planned contrasts were defined as follows:

Contrast 1 (C1) - Sad against Neutral + Happy + Angry based on a study, which showed that hazard perception was the most impaired for sad drivers (Zimasa et al., 2017).

Contrast 2 (C2) - Neutral against Happy + Angry. This compared low arousal and high arousal moods and was based on previous findings that high arousal mood is more detrimental for driving safety (Abdu, Shinar, & Meiran, 2012; Eherenfreund-Hager et al., 2017).

Contrast 3 (C3) - Comparison between the two high arousal moods - Happy against Angry. This determined whether there is a difference between two high arousal moods of different valence (Schwarz, 2000).

Planned contrasts were not conducted for the within subjects factor of Load as this was an exploratory variable with no a priori knowledge regarding the likely experimental effects.

The data were analysed by comparing the changes from the baseline to the corresponding mood, as mood was a between-subjects factor. This established changes in drivers' usual driving and glance behaviours as a result of mood induction. It permitted the assessment of whether the changes in Mood and Load conditions were due to an increase in one condition or decrease in the other. For example, if a significant difference in speed was found, that difference could be due to either an increase in speed in the angry mood or a decrease in speed in the sad mood. This method permits the monitoring of mood-related changes in more detail and the drawing of more robust conclusions. In addition, as the baseline drives were performed before mood induction, this method accounted for habituation. Dawson, Schell, and Filion (2007) defined habituation as a decline in physiological response with repetition of presented stimuli. This change analysis was performed on the driving performance, glance and physiological data.

3 Results

There were no significant differences in the baseline measures of all the dependent variables parameters between the four groups of participants, indicating that individual differences did not account for the observed changes. The analysis of the pre-study mood grid data showed that there were no significant differences in mood valence or arousal between the participants assigned to the different conditions (means=6.63 and 6.13 respectively on the 9 point scale). This indicates that the participants in each group were in approximately the same marginally positive mood and similarly aroused prior to the experiment.

The results are presented as follows: first the results of the mood induction are provided which establish the efficacy of the procedure. Following this, the results pertaining to the two main hypotheses are presented, whereby the effects of Mood and Load on driver performance and glance patterns are established. Finally, the results are summarised in Tables 4 and 5.

3.1 Mood induction

Self-reported and physiological measures were elicited in order to verify that mood induction had taken place. A two-way ANOVA was performed on valence and arousal with Mood (4 levels) being the between and Time Point (pre and post study) the within subjects factors. There was no main effect of Mood on self-reported mood valence or arousal.

However, there was a main effect of Time Point on valence, $F_{(1, 36)} = 19.16$, $p < 0.001$, $\eta^2 = 0.24$, with pre-study mood (mean = 6.6) being significantly higher than post-study mood (mean = 5.25). There also was a significant interaction, $F_{(3, 36)} = 8.59$, $p < 0.001$, $\eta^2 = 0.32$. Figure 3 shows that valence in the angry and the sad moods decreased after mood induction, indicating that participant's moods in these two condition became more negative.

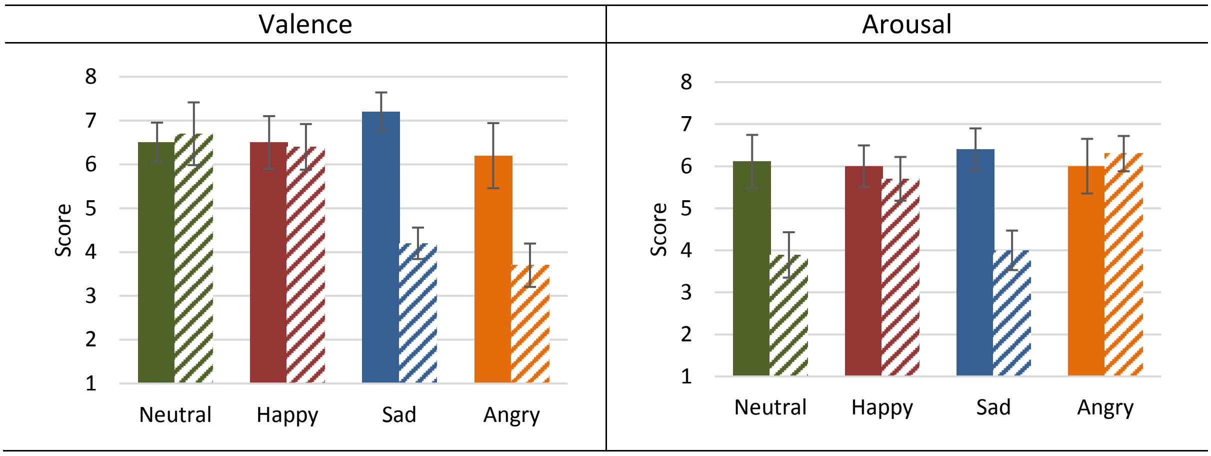

Figure 3: Self-reported mood valence and arousal for pre (solid bars) and post (striped bars) mood induction

There was also a main effect of Time Point on arousal, $F_{(1, 36)} = 22.05$, $p < 0.001$, $\eta^2 = 0.2$, with pre-study mood (mean = 6.13) being significantly higher than post-study (mean = 5.08). There also was a significant interaction, $F_{(3, 36)} = 4.4$, $p < 0.01$, $\eta^2 = 0.22$. Figure 3 shows that arousal decreased after mood induction in the neutral and the sad moods.

With regards to physiological data, there was a main effect of Mood on EDA χ^2 (3) = 21.76, $p < 0.001$, $\eta^2 = 41.3$, with mean ranks of 25.83 for the neutral, 12.00 for the happy, 29.55 for the sad and 10.50 for the angry moods, (Figure 4). There was also a main effect of Mood on HR χ^2 (3) = 23.2, $p < 0.001$, $\eta^2 = 37.5$, with mean ranks of 29.63 for the neutral, 12.90 for the happy, 24.00 for the sad and 7.50 for the angry moods.

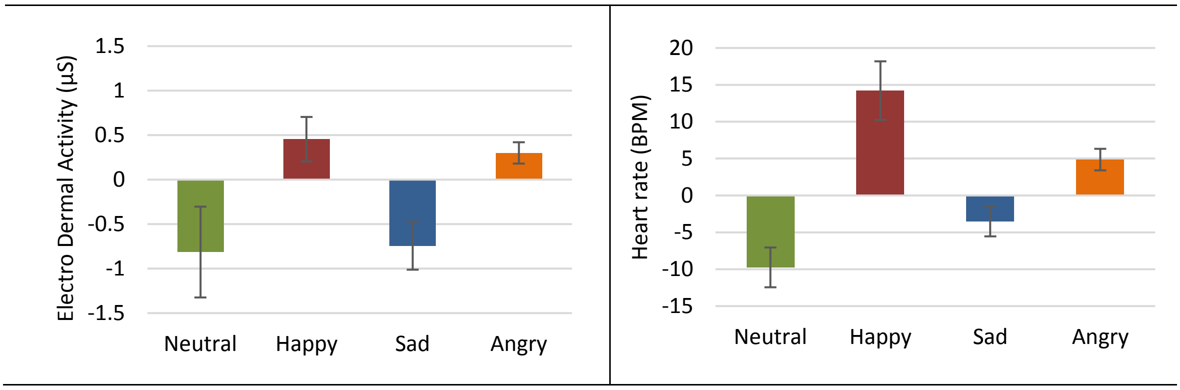

Figure 4: Changes in EDA and HR pre and post Mood induction

For both EDA and HR, pairwise comparisons showed the significant differences to be between the low (neutral, sad) and the high (happy, angry) arousal conditions (Table 2).

Table 2: Test statistics and p values for post-hoc comparisons of EDA and HR

	EDA		HR	
Mood comparison	**U- test**	**p value**	**U- test**	**p value**
Angry v Happy	0.46	1	5.4	1
Angry v Neutral	11.82	0.004**	22.13	0.00**
Angry v Sad	12.8	0.002**	16.5	0.006**
Happy v Neutral	10.89	0.006**	-16.73	0.005**
Happy v Sad	9.02	0.02*	11.1	0.11
Neutral v Sad	4.34	0.22	-5.63	1

Having established that mood induction was successful and that the different moods had varying effects on physiology and self-reported valence and arousal, the following sections address the hypotheses relating to the effects of Mood and Load on driving and glance behaviour.

3.2 Effect of Mood and Load on car following and time headway

There were no main effects of Mood and Load on the measure of coherence and no interaction effects. The minimum correlation was higher than 0.3 indicating that participants were engaged in the car following task, thus phase shift and modulus could be reliably analysed (see Section 2.5) (Brookhuis et al., 1994). For phase shift, there was a significant main effect of Mood, $F_{(3, 33)} = 3.4$, $p < 0.05$, $\eta^2 = 0.24$ (Figure 5). Planned contrasts showed that the sad mood initiated the biggest changes in phase shift from the baseline compared to other moods, $t_{(89.41)} = -4.78$, $p < 0.01$. There was no main effect of Load and no interactions in changes in phase shift.

With regards to modulus, there was a significant main effect of Mood, $F_{(3, 33)} = 3.63$, $p < 0.05$, $\eta^2 = 0.25$. Planned contrasts showed significant differences in modulus while sad, $t_{(32.3)} = -2.33$, $p <$

0.05 compared to all other moods. There was also a significant difference between the happy and the angry moods, $t_{(47.62)} = -5.01$, $p < 0.001$. There was no main effect of Load and no interaction (Figure 5).

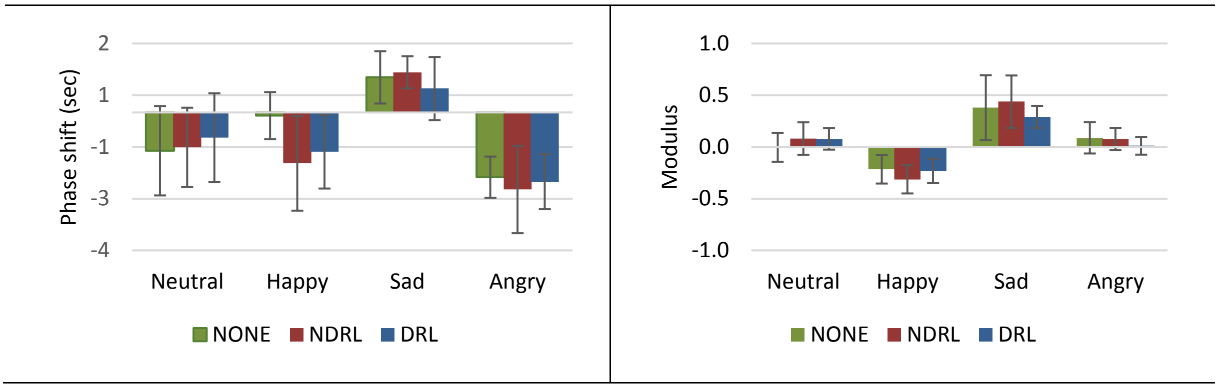

Figure 5: Phase shift and Modulus by Mood and Load

There was a significant main effect of Mood on TH only in 3-4 second time segment, $F_{(3, 36)} = 3.2$, $p < 0.05$, $\eta^2 = 0.21$ (Figure 6). In addition, the planned contrasts showed that the angry drivers significantly decreased the time spent at 3-4 seconds TH compared to happy drivers. The planned contrasts also showed that the sad drivers significantly decreased the time spent at shorter TH (less than 2 seconds) and significantly increased time driving at 4-5 seconds TH, compared to all other moods (Table 3, Figure 7). There was a significant main effect of Load in the 3-4 seconds time segment, $F_{(1.59, 57.27)} = 3.95$, $p < 0.05$, $\eta^2 = 0.1$. Post hoc tests showed that in the NONE condition drivers spent significantly more time in this time segment compared to the NDRL condition, $t = 2.81$, $p < 0.05$. There were no significant interactions.

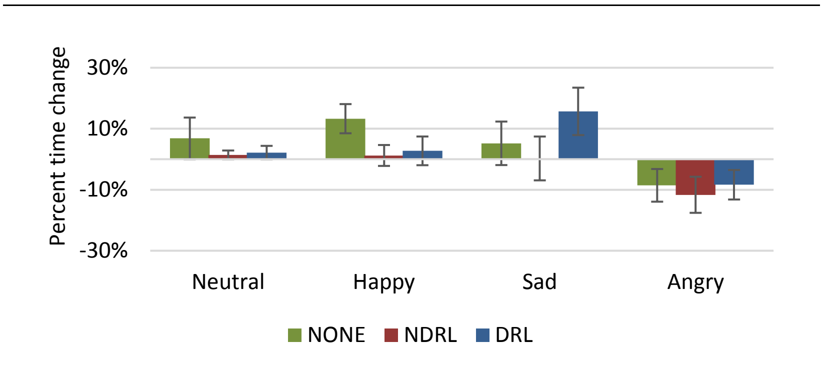

Figure 6: Time headway changes by Mood and Load

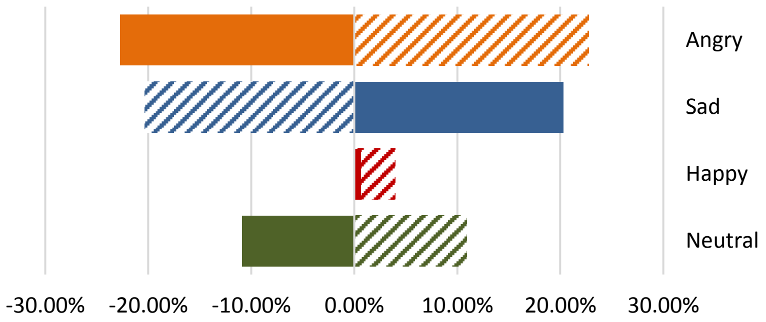

Figure 7: Changes in % time spent at TH < 2 seconds (striped) and TH > 2 seconds (solid)

Table 3: Inferential statistics for significant planned contrasts: C1 – contrast 1 (sad against neutral, happy and angry), C3 – contrast 3 (angry against happy)

TH	Contrast	*t* - value	*p* - value
0-1	C1	3.95	0.001
1-2	C1	3.13	0.01
2-3	C1	-2.28	0.05
3-4	C3	3.95	0.01
4-5	C1	-2.03	0.05
5-6	-	-	-

3.3 Effect of Mood and Load on glance behaviour

There was a significant main effect of Mood, $F_{(3, 36)} = 4.75$, $p < 0.01$ $\eta_p^2 = 0.28$ on fixation duration. The planned contrasts showed a significant increase in duration while in a sad mood compared to all others, $t_{(116)} = 2.55$, $p < 0.01$, whilst there was a significant decrease in the neutral mood compared to high arousal moods (happy and angry), $t_{(116)} = 3.58$, $p < 0.01$.

There was a significant main effect of Load, $F_{(1.71, 61.52)} = 9.23$, $p < 0.001$ $\eta_p^2 = 0.16$ whereby a decrease in fixation durations in NDRL compared to DRL was observed, $t_{(55.97)} = 2.64$, $p < 0.05$.

Finally, a significant interaction between Mood and Load, $F_{(5.13, 61.52)} = 3.86$, $p < 0.01$, $\eta_p^2 = 0.24$ was found. Within subjects contrasts showed that the difference was between NONE (mean -0.08 sec) and NDRL (mean 0.03 sec) in the sad mood. Between NDRL (mean 0.14 sec) and DRL (0.03 sec) in the happy mood there was also a marginally significant effect $p = 0.08$ (Figure 8).

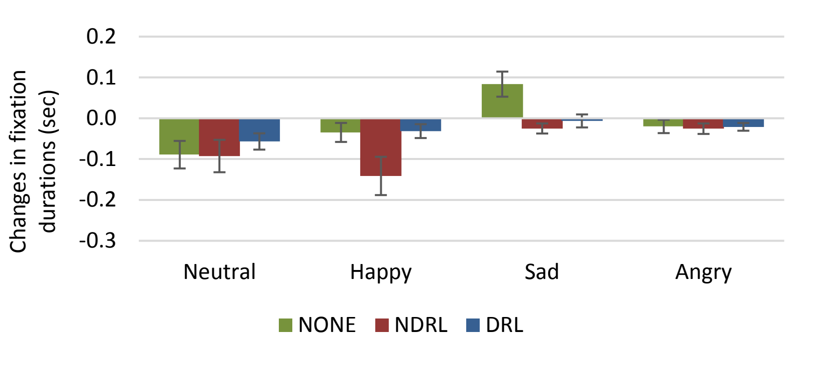

Figure 8: Changes in fixation durations from the baseline by Mood and Load

Moving onto the horizontal spread of fixations, there was a marginally significant main effect of Mood, $F_{(3, 36)} = 2.52$, $p = 0.07$, $\eta_p{}^2 = 0.17$ (Figure 9). Planned contrasts showed a significant narrowing in the spread of fixations while sad, $t_{(116)} = 2.64$, $p < 0.01$ compared to all other moods. On the other hand, the spread of fixations was significantly wider in the neutral mood compared to the high arousal conditions (happy and angry), $t_{(116)} = 2.77$, $p < 0.01$.

There was no significant main effect of Load and no interactions in changes from the baseline to the corresponding Load conditions.

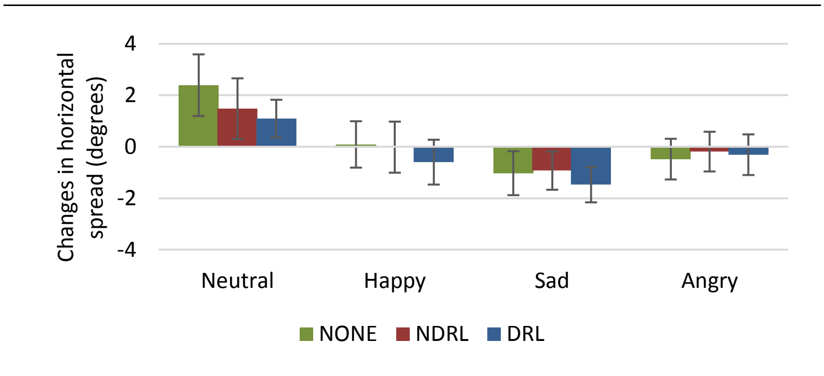

Figure 9: Changes in spread of fixations from the baseline by Mood and Load

3.4 Summary tables of results

A significant main effect of Load was observed only for fixation duration and TH in the 3-4 seconds segment, whilst interactions with mood were observed only for fixation durations (Table 4). The main effects of Mood and the contrasts are summarised in Table 5.

Table 4: Main effect of Load *F* values and effect size. Post hoc tests *t* values, and interaction

Measure	Main effect	Effect size	Post hoc	*t*	Interaction
Fixation duration	9.23***	0.16	NDRL-DRL	2.64*	3.86**
TH 3-4 seconds	3.95*	0.1	NONE-NDRL	2.81*	-

Table 5: *F* values, effect size, mood contrasts and associated with them *t* values for phase shift, modulus, time headway and glance measures

Measure	*F*	Effect size	Contrast Mood	*t*
Phase shift	3.4*	0.24	1	-4.78**
Modulus	3.63*	0.25	1 3	-2.33* -5.01***
TH 3-4 sec	3.2*	0.21	See table 3	See table 3
Fixation duration	4.75**	0.28	1 2	2.55** 3.58**
Horizontal spread of fixations	2.52	0.17	1 2	2.64** 2.77**

4 Discussion

The primary aim of this study was to investigate the effects of drivers' mood on measures of car following behaviour and glance patterns when performing a task that required sustained attention. Introducing low-levels of cognitive load to act as a distractor to mood-induced mind wandering to counteract any negative effects of mood was the secondary aim. The procedure used for mood induction (music with mental imagery) was successful in placing drivers in a variety of moods with different arousal and valence states, as evidenced by self-reports and physiological measures.

It was hypothesised that all induced moods, apart from neutral, would encourage mood-related mind wandering which would affect driver performance and glance patterns. Low levels of cognitive load (in the form of questioning) was hypothesised to disconnect participants from mind wandering. It was predicted that the efficacy of such an intervention would depend on relevance of the questions to the driving task; whilst non-driving related load (NDRL) was hypothesised not to have an effect, driving-related load (DRL) was expected to direct drivers' attention to the driving environment, and improve performance. In relation to drivers' mood, the hypothesis was supported, with the differing moods having varying effects on performance; for cognitive load, the hypothesis was partially supported. The results are discussed in more detail below, discussing each mood separately.

The neutral mood influenced car following behaviour only marginally, with no significant changes in some measures (modulus and coherence) but showing some unexpected trend towards improvement in reaction to the speed change of the lead vehicle (phase shift); this suggests some benefits of being in a neutral mood when sustained attention is needed. With respect to the choice of TH, the neutral mood did not influence this parameter in a consistent manner, apart from a tendency for drivers to reduce time spent at headways between 2-3 seconds. If the conclusions were drawn only from the driving performance (phase shift, modulus and time headway) results, then it could be argued that the neutral mood had only a marginal effect on driving safety. However, glance behaviour data provided additional insight. The decrease in fixation durations indicate an improvement in attentional shift and information processing compared to high arousal moods (happy and angry). In addition, the spread of fixations show that the drivers in the neutral mood exhibited a wider visual field compared to high arousal moods; this suggests that if an additional hazard were to present itself, drivers in the neutral mood would detect it more quickly and have more time to react appropriately (Chapman & Underwood, 1998; Crundall, Underwood, & Chapman, 2002; Crundall et al., 1998).

The happy drivers did not show clear patterns in any of the car following measurements. A decrease in phase shift indicated some improvement in sustained attention, but this was not significant. On the other hand, increased fixation durations, especially when NDRL was present, provides some evidence of mind wandering in this mood. However, the driver's visual field remained unchanged, as evidenced by the lack of change in the spread of fixations.

The effect of mind wandering on drivers in a sad mood was evident from both driving and glance behaviours. Only the sad drivers significantly increased phase shift compared to all other moods, suggesting an impaired ability to respond to the speed changes of the lead car. The drivers also significantly overshot (over-reacted), as indicated by modulus. With regards to TH, the sad drivers reduced the proportion of time spent below two seconds by approximately 20% and spent an additional 20% above two seconds, showing a preference for a larger safety margin to the car in front. An increase in TH has been interpreted as an action to accommodate drivers' performance (Winsum & Heino, 1996) and increases in drivers' cognitive load (Jamson, Westerman, Hockey, & Carsten, 2004). The question here is whether this increase is enough to accommodate an unexpected event? The glance measures suggest not. Increased fixation durations and narrower visual field provide evidence for impaired attentional shift and information processing. These findings support Pêcher et al. (2009) who also found that a sad mood is the most internal state of mind when drivers tend to focus on their own sad life issues, and psychological theories stating that sad individuals process information slower due to a systematic information processing manner (Luce, Bettman, & Payne, 1997).

At first sight, the angry drivers seemed to improve their driving performance (e.g. phase shift) or maintain it at a similar level to baseline (no or little change in modulus and glance behaviour). However, the angry drivers increased the time spent below two seconds TH by more than 20% and decreased in all other time segments. This suggests that the angry drivers preferred to drive closer to the car ahead. The question here is whether the increase in phase shift (improved response time) can compensate for such short THs if an emergency arose (e.g. a car merging from side junction). In addition, glance behaviour measures provide some additional insight into the angry drivers' safety behaviour in that there was no significant improvement in either fixation durations or spread of fixations. This implies that they might not have enough time to react should a hazard appear, due to a lack of adaptation in glance behaviour. The importance of peripheral vision in driving and the influence of cognitive load on a driver's ability to detect peripheral targets is well established in road safety research (Crundall, Underwood, & Chapman, 1999; Summala, Nieminen, & Punto, 1996; Wolfe, Dobres, Rosenholtz, & Reimer, 2017). Therefore, a decreased following distance with no associated change in visual search patterns could be disadvantageous in the event of a sudden hazard. These results highlight the importance of taking into account multiple parameters when assessing driving safety.

To summarise the effects of mood, the positive moods (neutral and happy) appear to have a positive, but limited, effect on driver's performance and their glance behaviour. In contrast the negative moods (sad and angry) can be seen to have much more definitive, yet different, effects. This raises the question, why does mind wandering affect the sad and the angry drivers differently? In information processing terms, a sad mood is known to encourage a systematic processing strategy, characterised by greater attention to detail (Schwarz, 2000) and focusing on one aspect at a time (Gasper, 2004; Luce et al., 1997). Thus, sad drivers "compensated" for processing self-focused thoughts by increasing their following distance. However, why did the angry drivers not also compensate for their internal thoughts? Averill (1983) differentiates anger from other emotions and suggests that anger is often expressed by aggression and that the aggression is not necessarily directed towards the source of the feeling. Often, individuals target unrelated inanimate objects or strangers. Abrams (2010) concluded that anger could increase concentration and facilitate achievements in sport. Possibly, drivers directed their angry feelings to the car ahead and task completion, thus decreasing their reaction times. This driving style can result in tailgating and road rage (Cai et al., 2007; James, 2000).

With respect to the effect of cognitive load on choice of TH, although there was a change in the amount of time drivers spent in the 3-4 seconds time segment, a clear pattern of results was not evident. It must be noted that the drivers were required to follow the car ahead for a relatively short period of time, and the cognitive load was not designed to interfere with driving safety and thus it may not have had the desired disconnecting power.

Similar to the effects of mood as reported above, cognitive load had clearer effects on glance behaviour, compared to car following and time headway measures. The results from this study show that NDRL had the most positive effect on glance patterns (fixation durations), suggesting that disengaging drivers from their internal thoughts by asking questions not related to driving, facilitates information processing. This finding supports previous research stating that mild cognitive load decreases mind wandering (Forster, 2013; Zhang & Kumada, 2017) and facilitates visual attention when driving on familiar roads (Young, Mackenzie, Davies, & Crundall, 2018). Conclusions can also be drawn from the interaction effects, whereby in the absence of load, mood has different effects on driver's glance behaviour. The sad drivers were the most affected by mood-related mind wandering when no questions were asked, compared to drivers in other moods. The absence of any load allowed them to sink into their mood undisturbed, whilst NDRL had a preventative effect by not allowing them to do so in the first place. In the happy mood, however, the non-driving related questions helped to actively disengage drivers' attention from mind wandering, encouraging them to process information faster. It should be noted however, this interaction was only marginally significant, warranting further research. Therefore, whilst on the surface, it appears that non-driving related load similarly affected those in sad and happy moods, it can be seen in Figure 8 that the sad mood, left un-checked, is the most detrimental to safety via slower information processing. The neutral and the angry drivers seemed not to be affected by cognitive load. It could be that the drivers in the neutral mood, not being affected by mind wandering, could cope with some amount of cognitive load, whereas the angry mood was too "powerful" to be affected by the type of load used in this study. Support for this can be found in sport psychology research (Lazarus, 2000; Rathschlag & Memmert, 2013; Woodman et al., 2009). For example, Rathschlag and Memmert (2013) argue that anger helps to concentrate on the target and positive emotions provide sufficient resources and motivation to pursue a demanding task. However, they found physical performance was significantly improved while angry, compared to the happy, the sad and the neutral conditions.

Five main conclusions can be drawn from this study. First, both dimensions of mood (valence and arousal) should be taken into account when assessing driving safety. Positive and negative moods can result in different behaviour depending on driver arousal. For example, sad and angry moods, regardless of them both being of negative valence, elicit different driving performance (e.g. time headway, phase shift and modulus) due to their differing arousal. Second, glance measures can complement driving performance measures and provide a more complete picture in mood-related safety assessment. Third, cognitive load can potentially be used to disengage drivers from mood-related mind wandering. However, more research is needed to determine what type and how much cognitive load is required to obtain the appropriate disengagement. Fourth, the disconnecting ability of cognitive load was not consistent in this study. However, it must be noted that this is the first study to attempt to use it as an intervention in mood research. The results are encouraging for more detailed research in methods of redirecting drivers' attention to the road and driving related issues in cases where mind wandering occurs. Further research which designs re-engagement techniques also must take into account that moods differentially affect drivers' attention (i.e. the sad and the angry). In cases where driving safety is evaluated by in-car driver assistance systems, multiple parameters should be taken into account. For example, a driver can maintain a high level of concentration while following a car ahead, but the duration of time that the drivers can maintain this is not clear. Intensively used attention resources can deplete and attentional failure could result in an accident. Thus the effect of time on attentional resources should be investigated in relation to drivers' mood. Finally, future research must take into account the fact that glance measures can be more sensitive to changes in drivers' mood compared to driving performance measures. Therefore, both measures should be collected where possible.

In terms of practical implications, automotive manufacturers are working towards the development of safer and more comfortable cars. Modern cars feature various driver assistance systems, such as cruise control, lane keeping assistance systems and workload managers. Workload manager systems, for example, attempt to assess whether the driver is overloaded or distracted and in such situations can delay vehicle system messages. For example, they can divert an incoming call to an answer machine in busy traffic situations, such as at junctions or sharp road bends (Green, 2004). Workload managers have been effective for drivers of different age groups and in situations with different traffic demands (Teh, Jamson, & Carsten, 2018). However, they do not take into account drivers' momentary mood and, in these situations, a driver's reaction could be affected. Thus, combining a workload manager with a mood recognition system (Kim, Bang, & Kim, 2004) could substantially improve driving safety. Moreover, these systems could monitor both overload and underload, recognise a driver's mood and arousal, and intervene for safer driving performance. Mood recognition systems could raise drivers' awareness of their momentary emotional state and thus enhance emotion self-regulation (Teper, Segal, & Inzlicht, 2013). In addition, various safety campaigns could be designed to increase drivers' awareness about possible hazardous road situations, such as 'speed awareness', 'safe distance' or 'parked cars'.

The present research shows that the less a driver is emotionally affected, the safer is their driving style and the better are their observational patterns. However, three main limitations should be noted: first, studies conducted in a driving simulator have been criticised for limited physical, perceptual and behavioural fidelity (de Winter, van Leuween, & Happee, 2012). Second, the sustained attention task was time-limited, and different results may have been found if it were to be extended. Third, several marginally significant results were found, indicating a trend in some effects of mood and cognitive load. Therefore, a study with a larger number of participants could help to clarify these findings. However, the assessment of driving safety based on several parameters (driving and glance patterns) has only just begun to be explored in mood research. Therefore, there is limited understanding of how exactly these parameters interact, especially in real driving conditions. The amount and type of cognitive load to help drivers combat the effects of mood-related mind-wandering warrants further research.

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Appendix - Questions asked during the drives

Driving-related load	Non-driving related load
What is the speed limit on this road?	What did you have for breakfast today?
Do you think it would be safe to drive faster on this type of road?	Can you hear this question clearly?
What if a car emerges from a side road?	Would you like to be on a sunny beach now?
Could there be a hazard after a road bend?	Do you have a dog?
What is appropriate speed for this road bend?	Do you like this music?
Is it safe to overtake the car ahead?	Do you like cycling?