Lessons from Emotional Driving Research

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Just as in other Human Factors research, driving behaviour research has focused on driver “cognitive processes”. Even though emotions and affect are critical components in people’s behaviour, their relationship with driving behaviour has not been systematically explored. The goal of this paper is to summarize our recent empirical findings on the effects of state affect on driving performance and related constructs. We have investigated real-time affective effects on driving using affect induction techniques and driving simulation, rather than depending on a survey method. We have considered incidental affect as well as integral affect to embrace more realistic situations. We have also focused more on discrete emotions (e.g., anger, fear, happiness, sadness, etc.) than dimensional affect (e.g., valence and arousal) to design adaptive mitigation interfaces to cope with each affect specifically. Empirical results in response to major research questions and future directions are discussed. This affect-driving research is expected to help to construct a generic research framework when modelling dynamic driving behaviours.

Practitioner Summary: Human Factors takes a systems approach, but has failed to include emotions and affect in its research agenda until recently. This is same in driving behaviour research. The present paper provides diverse components about affect driving research and empirical results of recent state affect research. Adding emotions and affect components to driving research will help researchers and practitioners in terms of better theory formation and practical intervention technology design.

Keywords: emotions, aggressive driving, road rage, distracted driving, driving simulation

1. Introduction

Driver distraction is one of the most critical factors of vehicle accidents. However, research has mainly focused on cognitive and physical distractions. Whereas there has been some research on emotions and affect in driving, little research has focused on “dynamic” affective effects. For example, Deffenbacher and colleagues [1, 2] have conducted survey studies about angry driving, in which the data heavily depend on participants’ memory instead of real-time driving. Moreover, a majority of research has concentrated on integral affect (driving-relevant) rather than incidental affect (driving-irrelevant) [e.g., 3-6].

Based on this background, we have created a new state affect-driving research protocol and conducted seven successive experiments [7-13] with robust affect induction methods, using multiple driving simulators. We included both integral affect (by manipulating driving scenarios) and incidental affect (by inducing a specific affective state). The present paper outlines overall lessons we have obtained from those studies and discusses future works.

2. Method

In total, 257 young drivers (M = 184, F = 103, Mean age = 20, Mean years of driving = 4.6 year) participated in seven experiments. We used a mid-fidelity NADS MiniSim simulator (Figure 1 (a)) and a low-fidelity SimuRide simulator (Figure 1 (b)). Both simulators included (existing or created) hazardous events across an urban and rural road, or a highway.

We used between-subjects design because having participants subsequently induce different affective states might negatively influence the results. Before inducing affect, participants were asked to rate their current affective states (baseline) using a seven-point Likert scale. After the simulator sickness screening protocol, they had 12 minutes to write a past emotional experience [e.g., 14] associated with specific affect (e.g., anger, fear, happiness, sadness) depending on their affect condition. Participants in a neutral condition...
wrote their mundane events of the previous day. Participants were urged to refer to two sample paragraphs in the instruction sheet to help them write their own paragraphs. In one specific experiment, participants also watched validated affect-induction video clips. After affect-induction procedure, participants completed ratings on their present affective states. Then, they were instructed to drive as they would drive in the real world, following any traffic and safety rules. After the drive, participants completed the final affective state rating and the NASA-TLX [15] to provide measurements of perceived workload. Finally, participants filled out a short questionnaire for demographic information.

![A participant drives in the NADS MiniSim driving simulator (a) and the SimuRide driving simulator (b).](image)

Figure 1. A participant drives in the NADS MiniSim driving simulator (a) and the SimuRide driving simulator (b).

### 3. Lessons

#### 3.1 Was affect Induction successful?

First of all, we successfully induced each affective state (e.g., anger, fear, happiness, sadness, and neutral, see Figure 2) using the combination of various affect induction methods. We measured participants’ affective states three times – before affect induction, after affect induction, and after the experiment. In all the experiments, regardless of types of affect, participants’ designated affective state ratings significantly increased after affect induction and decreased after the experiment. In most cases, affective state ratings after the experiment were still higher than before induction, which accounts for the source of their performance difference between affect conditions. Successful results of this affect induction imply that we can more widely use this affect-driving experimental protocol and we can also try to apply this induction method to other domains (e.g., online transaction) [e.g., 16].

![Affective states rating scores across rating timings. The scores increased after affect induction. After the experiment, affect scores decreased. All seven experiments showed that the similar patterns. Error bars indicate standard errors of the means.](image)

Figure 2. Affective states rating scores across rating timings. The scores increased after affect induction. After the experiment, affect scores decreased. All seven experiments showed that the similar patterns. Error bars indicate standard errors of the means.
Despite the promising results, it can be debatable whether the induced affective states in a driving simulator are equivalent to the affective states in actual driving. The affective effects in the actual driving context might be different (or larger) than in the simulator. However, the significant results of the simulation studies demonstrate that there is necessity for further affect-driving research.

3.2 Was driving performance different across affect conditions?

Given that all seven experiments included an anger condition, we can address the effects of anger on driving more clearly than any other affective states. Anger degenerated driving performance (i.e., increased overall driving errors, over speed, maximum speed, lane deviation, and aggressive driving behaviours, etc.) compared to the neutral condition.

Interestingly, happiness and sadness degenerated driving as much as anger, whereas fear did not show negative effects on driving (Figure 3 (a)). Two experiments consistently showed that the sadness and anger conditions showed significantly longer driving time compared to the neutral condition (Figure 3 (b)), with partial evidence of frequent lane departure.

3.3 Were there any effects of affect on other measures than driving performance?

After we induced affect, we asked participants about their driving confidence level, safety level, and perceived risk perception to see whether they expect their degenerated driving performance due to their affect induction. Only in one experiment [11], angry participants showed significantly lower safety level, but other than that, there was no other results, which indicates that they might not be consciously aware of their plausible risk.

In two experiments, driver situation awareness seemed to mediate between anger and driving performance either fully or partly. The association between affective states and speed-related performance variables (i.e., over speed errors and average speed) was fully mediated by SA. These full mediation models imply that affective effects appear only via the effects of reduced SA. On the other hand, the association between affective states and the number of collisions was partially mediated by SA. This partial mediation model implies that affective states can have an impact on the number of collisions either with or without the effects of SA. In other words, affective states could influence collisions through other plausible channels (e.g., motor planning and controlling). However, we cannot simply attribute the entire affective effects to situation awareness because there might be other steps where affect can still influence performance, such as decision making or action selection. Therefore, further research is still required to fully unpack the underlying mechanism(s).

For workload, we found mixed results. In most experiments, perceived workload was not different across affect conditions. Only in one experiment [10], anger showed significantly higher workload than neutral. We could partly explain this by the cognitive appraisal mechanism. For example, according to the cognitive appraisal, anger is deeply associated with ‘self-control’. Based on that, we cautiously infer that angry participants felt more workload during the new, frustrating (driving) task due to their failure of self-control.
than participants in other affective states. However, given that this workload difference was not shown in other experiments, we cannot fully explain why. One take home message is that affective effects seem to be different from workload effects. Therefore, we need to have different measures and a different remedy for affect.

3.4 What are plausible mechanisms to explain affective effects?
Driving researchers have said that “happy drivers are a better driver.” Also, affect researchers usually believe the “sadder, but wiser” phenomenon. Our empirical research shows that those notions are not working in the driving domain. Happy drivers were as bad as angry drivers. The difference might come from the degree of the affective state (e.g., normal happiness vs. excessive happiness). Regarding sadness, the different outcome might stem from the difference of the tasks. The traditional affect research on sadness has focused on the simple cognitive tasks, such as attention or decision making, whereas driving is a compilation of different levels of tasks, including attention, comprehension, projection, decision making, action selection, etc.

The above results imply that we might not be able to explain affective effects on driving depending on traditional affect mechanisms. Traditionally, the valence dimension has functioned as a good axis to distinguish affective states and has worked well in general. However, beyond the valence dimension, affective states may differ in various aspects, such as their autonomic manifestations, the extent to which they produce rumination or distraction, their evolutionary connections to mental and behavioural proclivities, and their tendencies to endure across time [17]. The arousal or activation has also served as a good axis. However, the optimal level of arousal may differ across task domains and situations. Given that affective states in the same valence or arousal dimension (e.g., both anger and fear belong to negative valence and high arousal) showed different performance results, we cannot account for affective effects by the valence or arousal dimensions.

The mood congruent effects or the cognitive appraisal mechanism partly explains the outcomes, but they cannot explain the entire results as well. Moreover, affective effects seem to be independent of perceived workload, which means that we need to adopt different approaches to affect other than traditional approaches. In sum, a more elaborated framework is required to disentangle complicated phenomena in driving-affect research.

3.5 Were there any plausible intervention strategies to mitigate affective effects?
In our research, listening to validated emotional music pieces (either happy or sad) significantly mitigated anger effects on driving performance [7] (Figure 4 (a)). However, there was no difference between happy and sad music conditions. The use of the in-vehicle speech-based systems not only reduced angry level and perceived workload, but also enhanced driving situation awareness, which led to better driving performance [8] (Figure 4 (b)).

![Figure 4](image-url)
Despite the similar promising results of the two types of speech-based system, the subjective assessment were different from those results. The emotion regulation (ER) type speech system was rated more ‘effective’ than the situation awareness (SA) type speech system. Participants might think that way because directive messages felt more ‘helpful’ in such a highly demanding situation, even with an angry state. Nonetheless, the ER system turned out to be more ‘annoying’ and more ‘authoritative’. Therefore, we might need to appropriately select either system depending on the target user.

3.6 What are the next steps?
First, our empirical state-affect research has shown that no overarching affect mechanism or theory can fully explain complicated phenomena. It does not mean that we do not need the traditional theory. Rather, based on what we have, we need more empirical research with other affective states to see if there is any emerging theory. Our previous study [18] has identified nine discrete affective states as important affect in driving contexts: fearful, happy, angry, sad, confused, embarrassed, urgent, bored, and relieved. So far, we have conducted research on first four affective states. With the rapid increase of in-vehicle technologies, confusion or embarrassment might also be of interest. When it comes to autonomous vehicles, boring or mind wandering can also be a good research topic. Positive affect also needs to be considered in addition to negative affective states when designing affect detection and regulation interfaces. Based on the results of our research, we infer that an attempt to change negative affect into positive affect may not be the best way to mitigate the affective effects on driving performance and safety. As can be seen in our study, an excessively happy state may serve as a distracter. Another positive state, such as ‘relieved’ may also not be an optimal state for driving because it may cause a delay in reaction time.

Based on these results and discussions, we could posit specific design directions for in-vehicle affect detection and mitigation interfaces. To estimate a driver’s affective states more accurately, we need to integrate more tools, such as body posture, eye-movement, facial expression, speech recognition, EEG, fEMG, and ECG [9], etc. In addition, more practical intervention strategies should be developed and tested to help drivers in affective states more appropriately. To illustrate, for drivers in an angry state, adaptive user interfaces can be developed to increase driving performance itself. Moreover, we might need to consider the prevention of drivers from developing the angry state into aggressive driving or road rage. For happy drivers, we might need to consider how to reduce driver distraction while maintaining their positive feelings. Particularly, happy and sad drivers need to be notified that they are in a risky state because they are not likely to perceive any risk or workload. For drivers in a fearful state, a regulation strategy to mitigate subjective feelings or stress level may be more suitable. Of course, for all affective states, the system should always alert drivers of the dangers and safety issues on the road.

We can also expand our driving population, including older adults, and specifically, drivers with traumatic brain injury (TBI) [19] or Post Traumatic Stress Disorder (PTSD) because they are particularly vulnerable to emotional issues. An investigation of affective effects in addition to secondary task effects is also of interest to mitigate complicated effects on driving performance and safety with a more sophisticated intervention.

To conclude, in order to help emotional drivers more effectively and efficiently, we need to recognize specific affective states and mitigate them with differentiated methods. All these efforts will ultimately contribute to revealing the theoretical relationships among important constructs, such as emotions, workload, situation awareness, and diverse driving performance measures.

References
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