Exploring the Perceived Cognitive Workload: The Impact of Various Scenarios and Emotions on a Driving Simulator

Buse Tezçi[1], Luca Tramarin[1], Edoardo Pagot[1], Marco Marchetti[2], Giuliana Zennaro[2], Paolo Denti[2], Stefano Giannini[3], Maura Mengoni[4], Silvia Chiesa[1]

[1] RE:LAB, Italy
[2] CRF, Italy
[3] Polito, Italy
[4] EMOJ, Italy

Abstract. Driver distraction due to emotional states gained attention in the last decades. Even though there are various studies examined and compared various emotions, so far changes in the emotional state was not examined. The aim of this paper was to explore the emotion-ordered effect on driver cognitive workload and contribute to the emotion distraction literature and draw practical implications for road safety. To study the effect, thirteen participants recruited for a driving simulator study and they were divided into two experimental groups in which they either tried Happy-to-Angry or Angry-to-Happy emotion transitions. Participants later assigned different driving scenarios. NASA-TLX data was collected after each scenario. Results reveal no statistically significant differences in perceived mental workload across different experimental conditions or their sequences, indicating consistent cognitive demands. However, observed trends suggest subtle variations that may require larger samples or more sensitive tools for detection.

Keywords: Driver distraction, Cognitive Workload, Affective distraction, Emotion order.

1 Introduction

The multifaceted demands of the driving task, with its myriad of simultaneous actions and the constant need to monitor and react to both internal and external stimuli, increases the likelihood of impaired driving performance. Consequently, driver distraction stands out as a prominent contributor to accidents, as individuals may struggle to maintain focused attention on the various elements demanding awareness while navigating the road [1]. Understanding the intricate dynamics of driving distraction is crucial for addressing and mitigating the risks associated with it, ultimately improving overall road safety.

The most commonly studied distraction types in the literature come in various forms, including physical, visual, auditory and cognitive and their combination as they can occur simultaneously [2]. In the past fifteen years, in addition to the “classic” distraction types, a new category was added and increasingly recognized due to its great impact on drivers’ performance is emotional distraction. The intricate interplay between emotions and driving behavior has been a subject of interest and concern in the field of transportation psychology [3].

1.1 Effect of emotional order on driving performance and cognitive workload

Numerous studies focused on comparing different emotional states, such as anger, boredom, sadness, happiness and examined their effect on driving behavior.

Initial and a limited number of studies on emotional distraction were conducted in mid-2010s.The main findings indicated that emotional valence of the content presented to drivers, whether a stimulus is positive or negative, had an influence on driving performance [4–7]. In the pioneer study done in emotional distraction research, Pêcher et al. [7] investigated the effect of emotional valence on driving behavior. Participants listened to happy, sad, and neutral music, neutral music served as a baseline where participants were most focused. Results showed that both sad and happy music led to deteriorations in driving behavior compared to neutral. These deteriorations varied between emotions: happy music caused more average speed decrease compared to neutral music and led to lateral control deterioration, while sad music, despite slightly decreasing mean speed, did not lead to longitudinal control deterioration. The participants reported to be aware of the distractive effect of happy music, but they were not aware of their reactions, such as following the rhythm of the song by tapping on the steering wheel. Authors suggested that especially, who are keen to be affected by happy music, might create a dual-task in which they increased their mental workload [7]. Similarly to auditory valence stimuli, visual stimuli with emotional content have been found to negatively impact driving behavior [8]. When participants were exposed to either negative or positive images before the hazard perception test, compared to neutral images, participants’ subjectively reported perception of risk was reduced, electrodermal responses was reduced and eye-fixation duration was shortened significantly, suggesting a inhibition of a reduced sensitivity to potential road hazards [8]. Visual emotional stimuli are also very interesting to examine, due to their abundance on the streets. In fact, in another study authors reported that driving speed is lower when negative and positive stimuli (roadside billboards) is presented compared to neutral stimuli [4]. It indicates that independently from valence emotion inducing content is distractive to the drivers, however, authors also observed that the length of distraction lingered for positive stimuli longer than negative ones. Contrarily, in an additional memory recall tasks that drivers conducted while driving, they had better memory retention with negative stimuli. These two findings suggest that, even though emotional distraction can be caused by either positive or negative stimuli, the mechanism and implications on emotional distraction is different.

Even though various initial studies have taken a closer look at the deteriorating effects of emotions on driving behaviour, some articles also showed an opposite effect in which negative emotion induced by negative videos increased the risk perception of the participants, even though this was not reflected on driving behavior. This was especially prevalent compared to positive emotions [9]. This might be due to the peculiarity of specific emotions, such as anger. Anger is a specifically examined case as experiencing anger leads to deliberate aggressive behavior as opposed to committing unintentional driving error [10]. Studies showed that anger affective state might deteriorate driving behavior due to reduced situation awareness [11] and caused more driving errors [11, 12] and affected driving behavior negatively by leading to higher maximum speed compared to neutral state [11]. Emotional distraction, specifically anger, was found to degrade the driving performance equally or more than other distraction types, such as physical or cognitive distraction [2]. Despite anger's particularity and negative emotions deterioration effect found in the literature, not only negative emotions but also positive emotions affect driving behavior.

There is a considerable level of enthusiasm surrounding this subject, especially among those seeking a comprehensive understanding of Advanced Driver Assistance Systems (ADAS) and Driver Monitoring Systems (DMS). This heightened interest is driven by the recognition that exploring the emotional dimension of driving can significantly enhance the development and effectiveness of ADAS and driver monitoring technologies. By gaining insights into how emotions influence driver behaviour, not only manual but also during partial-autonomous driving [13], these systems can be refined to not only detect and respond to physical distractions but also to consider and respond to emotional states, thus advancing road safety to new level [14].

1.2 Perceived Workload

Perceived workload is a common metric that usually accompanies the affective distraction studies and often assessed using subjective scales, such as the NASA-TLX [15]. However, the findings from these studies are heterogeneous. For example, while anger has been shown to negatively impact driving behavior and situational awareness, it did not significantly affect perceived workload in some studies [2, 8, 11]. Conversely, another study reported a significant increase in workload levels among participants in an angry state compared to a neutral state [12]. In the same study similarly, when comparing workload scores between sad and neutral states, a significant difference was observed, despite both emotional states leading to a decline in driving performance. This discrepancy was attributed to the distinct cognitive appraisals associated with anger and sadness. Anger, being more closely linked to self-control, may result in a higher workload when individuals perceive a lack of control in a frustrating driving environment, whereas sadness, associated with situational control, may lead to a lower perceived workload as individuals attribute the difficulty to external factors [12]. Additionally, a study comparing a boring auditory condition to neutral and interesting conditions found a significant difference in workload scores, albeit not substantial [16]. Even though various studies indicate that emotional states, especially anger, might lead to increased levels of cognitive workload, these varied results highlight the need for more studies and experimental conditions that include complicated emotional situations to shed a light on other aspects of cognitive workload.

Moving forward, it is crucial to consider the dynamic nature of emotions and their potential residual effects on driving behavior. While previous studies have examined emotional states independently, future research should explore the effects of emotional changes within the driving context. This is also important as literature also indicated there might be residual effects stronger for some emotions, for example positive ones [4]. For instance, examining the transition from a happy to an angry state or vice versa and its impact on driving behavior, such as changes in speed, can provide valuable insights into the role of emotions in driving performance. By incorporating complex emotional scenarios and examining emotional changes in the vehicle, researchers can gain a deeper understanding of the factors contributing to driver distraction and develop effective interventions to enhance road safety [17].

Drivers experience varying levels of drowsiness under different ambient lighting conditions, which is expected due to the natural association between lighting levels, time of day, and daily wake/sleep cycles. Research shows that during the day, when ambient lighting is high, drivers exhibit lower percentages of drowsiness. This can be attributed to the fact that daylight hours align with periods of heightened alertness in our circadian rhythms. Conversely, at night, when ambient lighting is low, drivers tend to show higher percentages of drowsiness. This increase is likely due to the body's natural inclination towards sleep during nighttime hours, making it more challenging to stay alert and focused [18].

Furthermore, studies examined the impact of various weather conditions on driver drowsiness and secondary-task engagement. However, the total number of events and epochs recorded during adverse weather conditions such as sleet, snow, fog, mist, and others was quite small. This limited data set suggests that the sample size might not be large enough to provide a comprehensive understanding of how these specific weather conditions influence driver behavior and secondary-task engagement. As a result, further research with a larger sample size is necessary to adequately address these issues and determine the true impact of different weather conditions on driving performance and drowsiness levels [18].

1.3 Hypotheses

In the light of findings of the literature, the following hypotheses were developed to be tested with the experiment.

- Hypothesis 1: The inclusion of various elements in the scenario will increase the difficulty of driving.

For instance, adding elements such as complex road layouts, varying traffic densities, and different weather conditions can increase cognitive load on the driver. Complex road layouts require more attention and decision-making, leading to higher mental strain. High traffic densities demand constant vigilance and quick reactions, which can further escalate the difficulty. Adverse weather conditions like fog reduce visibility and road traction, challenging the driver's ability to maintain control and respond to unexpected events. Consequently, these factors collectively contribute to a more demanding and potentially stressful driving experience.

- Hypothesis 2: Perceived workload (*NASA-TLX* scores) in conditions with different emotional sequence (from happy to angry and from angry to happy) will be different. The sequence in which these emotions are experienced can further impact the overall perceived workload. Transitioning from a happy to an angry state might result in a more pronounced increase in workload perception due to the sudden shift in emotional and cognitive demands. Conversely, moving from an angry to a happy state might lead to a significant reduction in perceived workload, as the positive emotions help mitigate stress and improve concentration. Therefore, both the type and order of emotions experienced play a crucial role in shaping the perceived cognitive demands of driving.

2 Method

2.1 Experimental design

The experiment was designed as a 2 (Emotional state order: Happy-to-Angry, Angry-to-Happy) x 3 (Driving scenario complexity: Smooth, Moderate, Difficult) mixed design. Therefore, half of the participants were assigned to the so called “Happy-to-Angry” group and half were assigned to “Angry-to-Happy” group. Independent from the assigned group each participant tried three different driving scenarios in a random order.

2.2 Participants

Consequently, the final dataset for analysis comprised thirteen participants, consisting of 7 females and 6 males, with average age of 30.8 (*M* =27.1, *Min=19; Max=41*). Regarding driving experience, 17% of the participants reported having less than three years of driving experience, while 58% indicated having between three to ten years of experience. The remaining 25% of participants reported having more than ten years of driving experience.

2.3 Materials

Driving simulator. The experimental research employed a static driving simulator, developed by Oktal-Scaner and powered by AVSimulation Scaner's simulation software. This simulator is equipped with authentic vehicle controls, including a force-feedback steering wheel, pedals for acceleration, braking, and clutch, a manual gear shift, and a cluster with various levers, including indicators. The seat is adjustable to accommodate drivers of varying heights, and simulator sounds are delivered through a stereo audio system. The simulator's architecture includes a projector screen, which displays the simulated environment in 1080p resolution at 60Hz. An LCD display behind the steering wheel presents the vehicle's instrument panel, while another touchscreen is positioned on the right side of the driver, mimicking a car's central console. Driving scenarios are designed using the Scaner Studio software suite, featuring a 3D terrain, a road network, traffic, and a storyboard of the scenario. The latter allows the user to program various custom actions by other traffic agents and to reproduce audio narratives to guide the testing subjects through the test.

Driving scenarios. Two highway driving scenarios and one citizen scenario were developed, each varying in traffic intensity.
Independently from the order of the emotions, the duration of each scenario was seven minutes. Participant tried both sessions in a random order.
In each scenario, participants tried either a change from angry emotion to happy emotion or happy emotion to angry emotion.
Following the baseline period, the emotional event is given by the pre-registered voice followed by a song. The "Happy" event refers to the cancellation of a chore or work-related task, allowing one to enjoy a recreational event. Conversely, the "Angry" event involves receiving a request from one's boss, leading to the cancellation of a recreational event, encountering increased traffic, and facing negative consequences due to the traffic. The music selection was based on the Cowen et al.'s taxonomy (https://www.ocf.berkeley.edu/~acowen/music.html#) [19].

In more details the Smooth condition is a scenario in highway. The driving simulation begins with an introduction where the participant is welcomed and instructed to drive and use the tablet and begin driving as they would normally. The simulation starts with free driving on a highway with medium traffic.
Next, in a joyful scenario, the participant drives on a highway with light traffic, informed that they are heading to the supermarket, which is about to close, but reassured that they will arrive on time.
The scenario then focuses on wellbeing, with the participant prompted to activate a speed camera alert. The highway remains lightly trafficked.
In the anger scenario, the participant encounters a slow-moving vehicle that they cannot overtake, risking the supermarket being closed before they arrive. This situation is designed to induce frustration.
A neutral state with visual distractions follows, where the participant is instructed to pick up and put down an object, say loudly some words and touch images on the tablet screen while driving.
The final segment involves coaching, where the participant is offered the option to use Adaptive Cruise Control.

The moderate scenario involves driving on a highway with heavy traffic.
During the joyful scenario, the participant is informed that he is driving to a work training course and the driver decides to listen to cheerful music to distract himself.
The scenario then shifts to coaching. The participant is given the option to activate the Automatic Emergency Brake by pressing a button on the screen.

In the anger scenario, the participant is warned that the traffic conditions are critical, making it certain he/she will arrive late to the course, which will already be in progress. Following this, a neutral state with visual distractions is introduced. The participant is instructed to pick up and put down a pen, loudly say some words, and touch images of on the tablet screen, all while driving on a heavily trafficked highway.
Finally, the wellbeing segment begins. The participant is offered the option to entertain himself by reading a joke by pressing a button on the screen.

The Dangerous scenario involves driving in a city at night with low traffic and foggy conditions.
In the joyful condition, the participant is driving with low traffic at night in the fog while heading to a work training course and he decides to listen to cheerful music.
The scenario then shifts to coaching. The participant is given the option to activate the auto hold feature, which keeps the vehicle stationary after braking, useful in traffic or on inclines, by pressing a button on the screen. The driving conditions remain the same, with low traffic at night in the fog.
In the anger scenario, the participant is warned that the traffic conditions are critical, making it certain they will not arrive on time to the course. This situation is designed to induce frustration.
Following this, a neutral state with visual distractions is introduced. The participant is instructed to pick up and put down a magazine, say some words aloud, and touch images on the tablet screen, all while driving in a city at night with low traffic and fog.
Finally, the wellbeing segment begins. The participant is offered the option to entertain themselves by reading a joke by pressing a button on the screen.

In the Angry-to-Happy condition the scenario is the same but with the emotion conditions in the opposite order.

Questionnaires.

Demographic information. Demographic information is collected from participants including age, education level, and driving habits.

After-session questionnaires: *NASA-TLX (NASA Task Load Index).* NASA-TLX questionnaire was used after each driving session to obtain workload induced by each scenario on participants.

The questionnaire s a widely used subjective assessment tool designed to evaluate perceived workload in various tasks, including driving. The NASA-TLX assesses workload along six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration level.

Participants rate each dimension on a scale from 0 to 5, where 0 represents "very low" and 5 represents "very high." These ratings provide insights into the subjective experience of workload associated with the task being evaluated.

2.4 Procedure

Participants were assigned to two groups with reversed orders of simulated emotions. The first group experienced the "Angry-to-Happy" scenario, while the second group underwent the "Happy-to-Angry" scenario.
To commence the study, participants filled out an entry questionnaire. Subsequently, participants provided information about their knowledge of ADAS, DMS systems, and sensors, along with any relevant experiences.
Once the entry questionnaires were finished, the experimenter exited the room, instructing participants to follow the pre-registered voice commands. Participants were left alone in the driving simulator room, where the emotion recognition software began registering their emotions throughout the experiment. Participants followed the voice prompts and completed the scenario. Following the conclusion of the first scenario, the experimenter re-entered the room and administered the after-session questionnaire.
Upon completion of the questionnaire, the second session commenced, followed by the second after-session questionnaire. Subsequently, the third session was conducted, accompanied by the third after-session questionnaire. Following the conclusion of all three sessions, participants filled out the end-questionnaire.

3 Results

Statistical analysis completed with IBM SPSS Statistics Version 29.0.2.0 (20) software.

3.1 NASA-TLX

The results of the NASA Task Load Index (NASA TLX) indicate that there is no statistically significant difference between the experimental conditions under investigation ($F(2,10)=3.69$; $p=.06$). This lack of significance suggests that, based on the subjective workload assessments provided by the participants, the varying conditions did not result in perceptibly different levels of mental workload. This finding implies that the conditions, despite their differences, are not perceived as varying cognitive demands on participants.

Moreover, when comparing the specific sequences of conditions, A-H and H-A, the results similarly show no significant difference ($F(2,10)=1.51$; $p=.23$). This consistency further supports the idea that the order in which these conditions are experienced does not affect the participants' perceived workload. Such a finding is important for experimental design, indicating that counterbalancing the conditions or the sequence in which they are presented does not introduce bias into the results.

However, it is worth noting that while the differences are not statistically significant, the data do exhibit a trend. This trend, although not robust enough to achieve statistical significance, suggests there might be subtle variations in how participants experience the workload under different conditions. These trends can be indicative of underlying patterns that could become significant with a larger sample size or with more sensitive measurement tools.

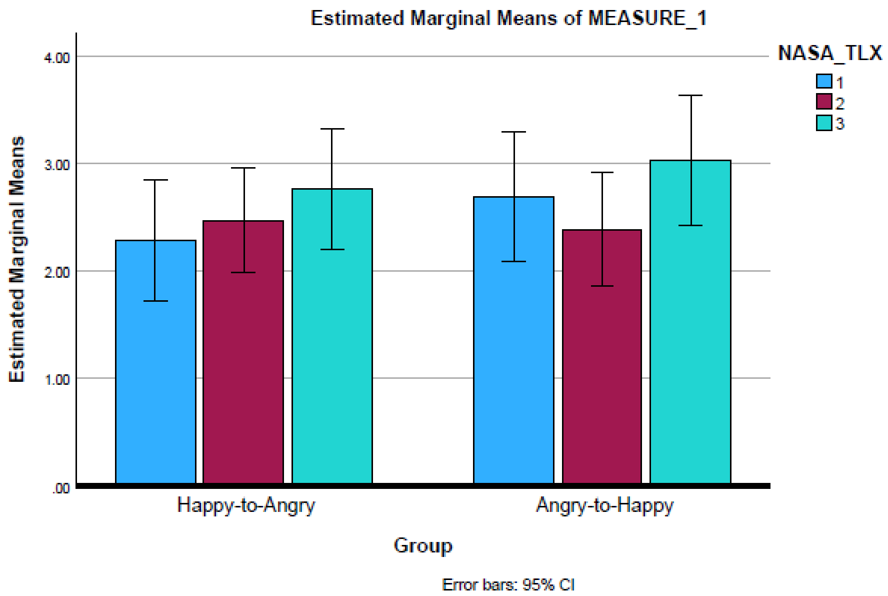

Figure 1. Results of the Nasa-TLX in the three conditions (1: Smooth; 2: Moderate; 3: Dangerous)

4 Discussion

The NASA TLX results demonstrate no significant differences in perceived workload across the conditions or their sequences, implying consistency and reliability in the participants' workload assessment. This consistency is crucial as it suggests that the different experimental conditions, and the order in which they were presented, do not lead to varying levels of perceived cognitive demand. This reliability in workload assessment is essential for ensuring that the results are not influenced by extraneous variables or the sequence of the conditions.

However, despite the lack of statistically significant differences, the data exhibit trends that suggest there may be subtle variations in perceived workload that are not captured due to the current sample size or methodology. These trends are important as they hint at underlying differences that could become significant with further investigation.

For instance, increasing the number of participants could enhance the power of the study, making it more likely to detect small but meaningful differences in workload across conditions. A larger sample size would provide a more robust dataset, reducing the margin of error and increasing the confidence in the findings. Additionally, refining the methodologies used, such as employing more sensitive measurement tools or adjusting the experimental design, could help uncover these nuanced differences.

Conducting further analysis with the gathered data is essential to comprehensively understand the nuances of the experiment. By incorporating additional sources of information, such as simulator data, emotional responses, and supplementary questionnaires, researchers can gain a more comprehensive understanding of the factors influencing the outcomes. This multifaceted approach allows for a more detailed exploration of potential differences and provides a more robust basis for drawing conclusions.
Simulator data, for instance, can offer insights into participants' behavior and performance in simulated environments, providing context to their subjective workload assessments. Emotion data can shed light on the emotional experiences associated with different experimental conditions, which may influence perceived workload. Additionally, supplementary questionnaires can capture additional variables or perspectives that may not have been addressed in the initial assessment.

Furthermore, it appears that the sequence or order in which the emotions are experienced does not have a discernible impact on the perceived cognitive workload, suggesting that the subjective assessments of workload remain consistent regardless of the emotional context in which they occur. This observation underscores the reliability and stability of the participants' workload evaluations, reinforcing the validity of the study's conclusions. Additionally, it implies that variations in emotional states do not significantly alter individuals' perceptions of the cognitive demands imposed by the experimental conditions.

4.1 Limitations.

Based on the previous results, it is important to acknowledge limitations that may have influenced the study outcomes. These limitations should be addressed in future research to build upon the current findings and provide a more comprehensive understanding of the relationship between emotions, cognitive workload and driving behavior.

Lack of neutral group. While the study effectively controlled for the order of experienced emotions, and included a baseline driving period at the beginning of the driving session, the absence of a neutral group remains a limitation. To address this in future studies, it is recommended to incorporate a third neutral group that will undergo each driving scenario with a neutral stimuli that will not induce an emotion in the participants.

Driving experience. Systematic studies indicated that novice drivers’ hazard perception skills may not be as refined as those of experienced drivers [21, 22] potentially leading to a heightened tendency to feel nervous and uncomfortable during driving [3]. Consequently, even though only 17% of the sample consisted of drivers with less than three years of driving experience, lack of driving experience might have influenced driving behavior. Therefore, future studies, should aim for a more balanced sample to better compare and control for the effect of experience.

Number of participants. One limitation of the study is the restricted number of participants, which could affect the robustness of the findings. With a limited sample size, the statistical analyses may not have sufficient power to detect subtle but potentially important trends. Increasing the number of participants in future research endeavors could enhance the reliability and generalizability of the results, potentially uncovering more definitive conclusions about the impact of emotional states on perceived cognitive workload in driving scenarios.

5 Conclusion

Our study investigates the connection between emotions, cognitive workload and driving behaviour. As we move forward in the pursuit of safer roads and the integration of autonomous vehicles, it is essential to consider the emotional dimension of driving. By doing so, we can develop more effective strategies to mitigate distractions, enhance driver safety, and, ultimately, reduce the incidence of road accidents [20, 21]. This research contributes to a growing body of knowledge that can inform policies and practices aimed at making our roads safer for all.
In conclusion, the NASA TLX findings indicate that the experimental conditions and their sequences do not significantly affect perceived mental workload, ensuring consistency in cognitive demands across different scenarios. While the lack of statistical significance suggests robustness in the experimental design, the observed trends point to potential subtle differences that merit further investigation with larger samples or more refined measurement methods. This insight is crucial for designing future studies and understanding the nuances of cognitive workload assessment.

Driver cognitive workload, a prominent contributor to accidents, necessitates a comprehensive approach to mitigate risks and enhance road safety. Understanding the methodologies to better study this aspect is important to grasp the effective impact of driving scenarios on cognitive workload, as well as the influence of emotions on driving performance. The interplay between emotions and driving behavior is a significant concern in transportation psychology, with research indicating that emotional states can elevate cognitive workload levels. Therefore, a nuanced understanding of these factors is essential for developing strategies to improve driver safety and performance.

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