Evaluating Emotion Regulation Techniques for Supporting Driving Safety and Performance

November 2023 | Final Report

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. TTI-Student-09	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluating Emotion Regulation Techniques for Supporting Driving Safety and Performance		5. Report Date November 2023 6. Performing Organization Code:
7. Author(s) Sahinya Susindar - 0000-0003-4684-3380 Thomas Ferris - 0000-0002-4326-5784		8. Performing Organization Report No.
9. Performing Organization Name and Address: Safe-D National UTC Texas A&M Transportation Institute 3135 TAMU College Station, Texas 77843-3135		10. Work Unit No. 11. Contract or Grant No. 69A3551747115/TTI Student 09
12. Sponsoring Agency Name and Address Office of the Secretary of Transportation (OST) U.S. Department of Transportation (US DOT)		13. Type of Report and Period Final Research Report 14. Sponsoring Agency Code

15. Supplementary Notes

This project was funded by the Safety through Disruption (Safe-D) National University Transportation Center, a grant from the U.S. Department of Transportation – Office of the Assistant Secretary for Research and Technology, University Transportation Centers Program.

16. Abstract

People operating motor vehicles are often required to engage in decision-making while under substantial cognitive loads imposed by the driving environment. In such situations, distractions, both external and internal, can compromise the safety of individuals and the system. Driving under the influence of elevated emotions has been shown to increase the risk associated with driving by 10 times compared to driving in a calmer emotional state. Aggressive driving behaviors, which include driver interaction with other drivers on the roadway, lane change behavior, and speeding, are often associated with rage and anger, but they are also seen in the experience of elevated states of happiness. Therefore, there is a need for interventions to de-escalate elevated emotional states in a manner that improves driving safety and performance while imposing minimal additional load on the driver to engage with these interventions. This study employed three interventions that utilized different sensory modalities and a range of cognitive demands from the driver and compared them to driving under anger and happiness with no intervention. Results suggest that the use of interventions can have a positive effect on aspects of driving, such as tailgating, speeding, and yellow light behavior, as well as the driver's workload.

17. Key Words Emotion regulation techniques, transportation safety, driver decision-making, elevated emotional states, driver performance	18. Distribution Statement No restrictions. This document is available to the public through the Safe-D National UTC website, as well as the following repositories: VTechWorks, The National Transportation Library, The Transportation Library, Volpe National Transportation Systems Center, Federal Highway Administration Research Library, and the National Technical Reports Library.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 23	22. Price $0

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Acknowledgements

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The authors are grateful for the assistance of the following individuals in the development of materials for and execution of this study: Nathaniel Krall, Maja Schermuly, Taylor Pham, and Harrison Wissel-Littmann.

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Introduction

The number of motor vehicle fatalities within the United States is estimated to be around 37,000 annually, which is over 100 fatalities per day (National Highway Traffic Safety Administration [NHTSA], 2018). An analysis of over 2 million crashes revealed that driver decision errors are primary contributing factors in 33% of fatal crashes (Singh, 2018). One major influence on the occurrence of these decision errors is the emotional state of the driver. Dingus et al. (2016) found that driving in an elevated emotional state increased the risk associated with driving by a factor of 10 compared to the risk associated with driving in sober, alert, and attentive states. In accordance with these findings, NHTSA has identified strong emotions as cognitive distractions that may lead to dangerous driving situations (NHTSA, 2009).

There are two primary ways in which emotional state can affect driver performance and safety. First, emotions can influence the driver's perception of risk-related information and the levels of risk that they are willing to accept when considering potential courses of action (Loewenstein & Lerner, 2003). Second, the activities and efforts associated with managing one's emotions may negatively influence driving safety because this emotional management imposes demands that compete for cognitive processing resources that are engaged in driving the vehicle (Gordon, 2005; Wickens, 2002).

Studies of emotions and driving behaviors have shown that emotional states characterized by high arousal and extreme valence (very positive or very negative emotions) are especially distracting and potentially detrimental to the driving task (Grimm et al., 2007). As illustrated in Figure 1, these high-arousal states can be either positive in valence (such as energetic happiness and excitement), or negative in valence (anger and frustration). In addition to high-arousal emotions, emotional states associated with low levels of arousal and negative valence (such as boredom or sadness) have been shown to degrade driving task performance (Grimm et al., 2007). Emotions with a negative valence are more likely to significantly influence driving behavior compared to positive emotions (Hu et al., 2013). In general, emotions with a negative valence increase the driver's risk propensity (tendency to take or avoid risks). Individuals with high propensity for risk are risk-takers, and those with low propensity for risk are risk avoidants (Chen et al., 2011; Doctor, 2015; O'Neill, 2001; Spulick, 2015).

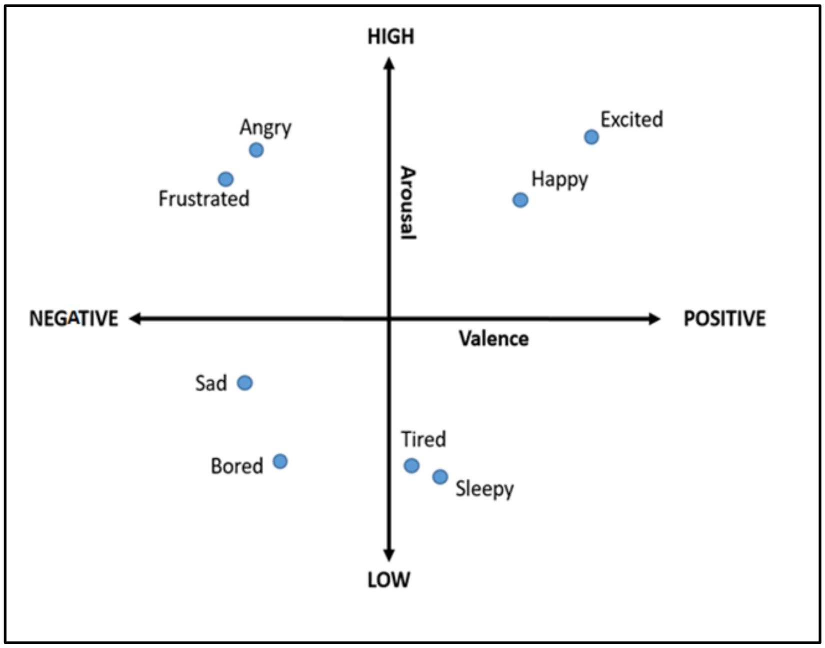

Figure 1. Chart depicting driver emotions on a valence-arousal scale.

There are a variety of educational, legal, and social approaches to address transportation safety problems posed by elevated driver emotional states. Drivers' education programs can incorporate educational modules that illustrate the dangers of "road rage" (e.g., driversed.com; twdrivingschool.com). Public safety announcements and awareness campaigns can bring attention to the influence of emotional states and mitigate their negative effects (NHTSA, 2018). Technological solutions of the near future may include vehicle-embedded "emotion sensing" technologies (e.g., Elgan, 2019). With an enhanced awareness of a driver's emotional state, driver-centered vehicle system solutions could then trigger assistance protocols to help the driver control their emotional state or mitigate the behavioral consequences of that state.

Another solution, emotion regulation techniques (ERTs), can be introduced to help an emotional driver reduce the intensity (magnitude) of the experienced emotion and/or shield decision-making from the effects of this emotional state (Lerner et al., 2015). Some strategies that have been studied include time delay (Gneezy & Imas, 2014), emotion suppression (Heilman et al., 2010), cognitive reappraisal (Heilman et al., 2010; Jamieson et al., 2012), and affect misattribution awareness (Lerner et al., 2015; Schwarz, 2000; Schwarz & Clore, 1983). Emotion regulation in the driving context may also introduce safety risks if it represents additional tasks or distractors. The current study evaluated the effectiveness, driving performance, and safety implications of a representative set of ERTs to illustrate the potential benefits of integrating ERT assist systems into vehicles.

Background

Operating a motor vehicle can sometimes impose a substantial cognitive load on the driver. If drivers are also experiencing elevated emotional states, managing these states can impose additional cognitive loads, potentially constraining cognitive functions engaged in decision-making. The influence of emotions on driver decision-making can be minimized by employing strategies targeted at reducing the intensity of the emotion. Regulation strategies can engage different perceptual and cognitive channels to minimize competition between perceptual/cognitive resources. For example, ERTs can minimally interfere with the visual, manual, and spatial processing demands of vehicle control (Wickens, 2002; Yang & Ferris, 2019). Examples of auditory-based ERTs include presenting voice prompts, music, or emotionally charged sounds. Harris and Nass (2011) showed that it is possible to use voice prompts to initiate cognitive reappraisals that can regulate the effects of elevated negative emotional states. Jeon et al. (2011) found that simple voice commands like "take a deep breath" or "relax your grip on the wheel" could reduce anxiety in anxious drivers. Such auditory ERTs are plausible methods to regulate emotion, but they may not be ideal to introduce in a driving context. Such ERTs require effortful rationalization and conscious engagement of cognitive resources, thus potentially competing with the resource demands of concurrent driving tasks, which may lead to driving performance decrements (Harris & Nass, 2011; Jeon et al., 2011; Wickens, 2002). Therefore, selecting ERTs requires considering both the potential benefits in emotional regulation (and the subsequent safety improvements with regard to risk-related decision-making) and the potential negative impact of allocating cognitive resources to the ERT on driving performance and safety.

As a result, ERTs that require minimum cognitive engagement, and perhaps even work subconsciously, may be well suited for supporting drivers in an active driving context.

ERTs Emphasizing Minimal Associated Cognitive Demands

Emotions are unstable and temporary, and they are susceptible to environmental changes that allow people to regulate them either with or without conscious awareness (Payne & Cooper, 2003). These qualities of emotions make it possible to design ERTs that require minimal cognitive resources and can be embedded in the driving environment.

Sense of smell has a strong connection with elements of human emotions, and scents can be used to alter moods, increase alertness, or relax (Dmitrenko et al., 2020). Scents normally associated with positive valence (such as rose, vanilla, etc.) may be used to regulate elevated negative emotional states by eliciting a positive emotional response (Dmitrenko et al., 2020). The scent of rose was found to improve driving performance via speed reduction and fewer lane deviations (Dmitrenko et al., 2020).

Within auditory processing, musical parameters can be manipulated to elicit emotions. For instance, simple and consonant harmonies, staccato articulation, wide melodic ranges, faster tempos, and brighter timbres are some musical parameters that can express happiness. Conversely, complex and dissonant harmonies, legato articulation, narrow melodic ranges, slower tempos, and darker timbres can be used to induce sadness or other negative emotional states (Berg & Wingstedt, 2005).

The current study evaluated the effectiveness of three ERTs that varied according to the sensory channels engaged (visual, auditory, and olfactory) and the levels of cognitive processing demand they impose on the user. While driving under certain emotional loads, participants were instructed to complete scenarios with embedded risks to driving safety and performance. ERTs that engage hearing, scent, and vision were introduced and compared with non-ERT contexts for the effects on metrics representing aggressive driving behaviors, such as speeding, tailgating, and yellow-light behavior. The workload imposed when engaging each ERT while driving was also measured.

Method

This study was designed to assess 1) the effect of induced emotions on driver risk-taking and decision-making and 2) relative effectiveness of various ERTs in reducing behaviors considered risky in the driving context. Two emotional states were considered, and the study had four ERT conditions, one of which is a control group without any ERT intervention. Driving safety and performance were assessed based on the impact of these two variables on driving risk propensity, tailgating behavior, and imposed workload.

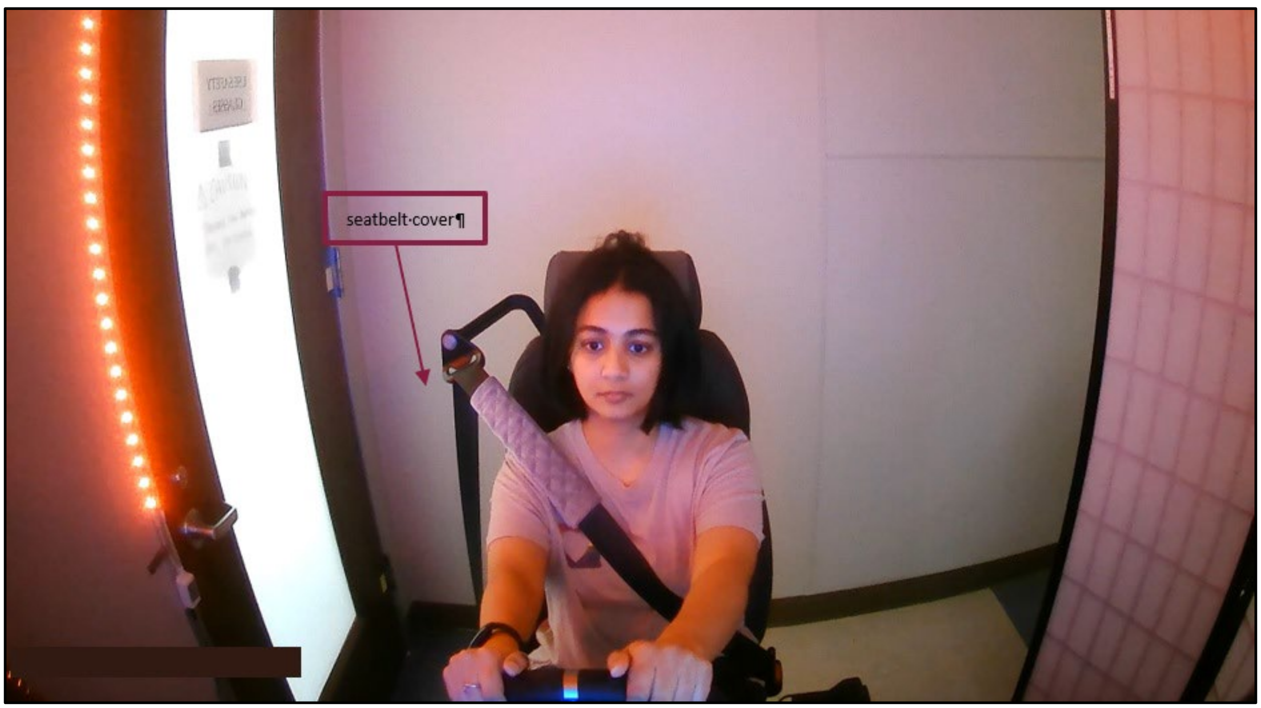

Figure 2. Photo of the driving environment for anger conditions.

Independent Variables

Target Emotions Elicitation and Maintenance

The target emotions were anger and happiness, which are both commonly experienced emotions in the driving context and are also associated with high arousal. Stimuli were presented through multiple sensory channels for a higher degree of immersion using elements such as virtual reality, ambient lighting, sound, and involving the participant in a scenario to elicit anger and happiness (Figure 2).

The emotion elicitation for anger was supplemented with red ambient lighting (associated with high arousal and anger feelings; Lee, 2019) and a high-pitched ringing noise designed to pause for random intervals of time to introduce uncertainty about when and for how long the sound would be present. The high-pitched noise was played for most of each anger trial. If they asked about it, the participants were told that the room they were in was situated below a machining lab that often produced such sounds.

Happiness was elicited using techniques often used in casinos—lights, music, good luck, and reward. This involved a carefully constructed series of steps, beginning with luck and reward using a "wheel of fortune" that the participants would spin and win $5 (Figure 3). To maintain participants in a positive, high-arousal emotional state, the ambient environment was enhanced with exciting video game music and saturated purple ambient lighting. The wheel was programmed to always land on "winner," but each participant was informed that their odds of winning were 1 in 8 and that few to no other participants had won so far. To add to this, each participant was told that they were given a chance to "spin the wheel" as a reward for a legitimate action the participant took. For example, individuals who participated on weekends were told that they were rewarded for participating on a weekend. A win on the wheel rewarded each participant with $5 in addition to their expected compensation for the study ($10). The investigators then exclaimed their surprise, congratulated the participant for winning, and continued to express their disbelief and happiness for the participant.

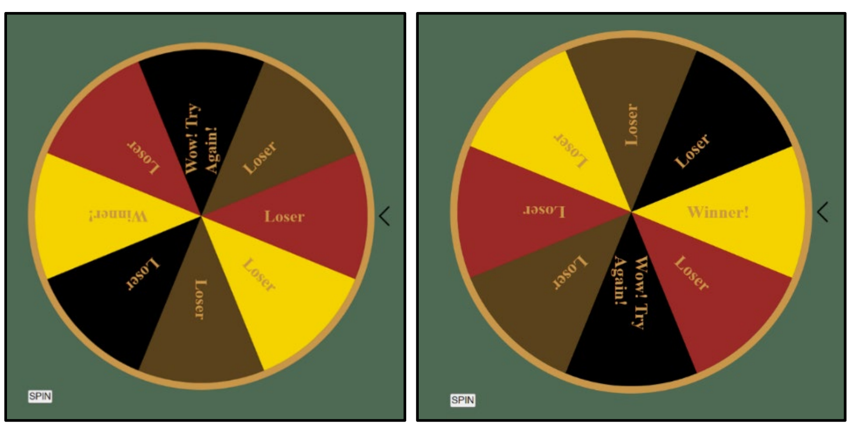

Figure 3. Illustrations of the "wheel of fortune" designed for use in this study.

ERTs

This study employed three ERTs that engage different sensory channels and have varying levels of resource demands. This study also included a control condition without any ERT, referred to as No ERT or NERT.

Visual ERT

The visual ERT (VERT) was a paced breathing application, with visual guides, that was mounted near the console to mimic a common placement for a mobile device in vehicles. The device with the application was adjusted, for each participant, so they could see it without making additional head movements (Figure 4). The breathing guide was set for 5 minutes and started approximately 2 min and 30 seconds after the beginning of the driving scenario. Participants were asked to follow the application to the best of their abilities without pausing the drive to give their undivided attention to it. The ratio of inhalation to exhalation was set for 4:4 with a 1-second hold between each. According to Oneda et al. (2010), slow breathing, i.e., fewer than 10 breaths (inhalation and exhalation) per minute can decrease sympathetic activity and aid relaxation. One slow-breathing technique is the box-breathing method (Priya et al., 2021), which traditionally has a 4:4 inhalation-to-exhalation ratio with 4-second holds between each (Priya et al., 2021). However, 4-second holds were challenging to many individuals (Dar et al., 2022), and holds were consequently reduced to two 1-second holds between inhalation and exhalation. This ratio also satisfies the criteria for slow breathing, as it results in fewer than 10 breaths a minute and was found to induce a sense of "calmness" in previous studies (Susindar et al., 2019). Participants were informed that this ratio could be changed if they were uncomfortable.

Auditory ERT

The auditory ERT (AERT) utilized an 8-min sound clip, "Weightless" by the Marconi Union (2014), that was designed with a continuous rhythm of 60 beats per minute, low underlying bass tones, and a low whooshing sound to induce a sense of "calm" in the listener. This clip has been shown to reduce anxiety and calm highly anxious individuals (Rather & Shrivastava, 2019; Telegraph Media Group, 2011) and was played to the participants through a pair of headsets at a volume level that participants deemed comfortable. The music started playing approximately 2 minutes into the drive.

Scent-Based (Olfactory) ERT

The scent-based ERT (SERT) utilized the scent of lavender, which has been shown to improve parasympathetic activity and to induce calmness (La Torre, 2003). The "Astura, Mist Your Mood" lavender spray was used in this study. The scent was sprayed onto a seatbelt cover (shown in Figure 2), and all participants in this study were required to wear their seatbelt and place the cover near the upper part of their torso (chest to shoulder). Participants were told that there were complaints about the seatbelt being uncomfortable, and therefore they should place the cover near their chest and shoulder. This spray satisfied our need for a short-lived scent that would be localized to the seatbelt cover and would not have any lingering scent once the cover was removed and taken away. When not running a participant in the SERT condition, the scented seatbelt cover was replaced surreptitiously with an identical, unscented cover.

Emotion Assessment

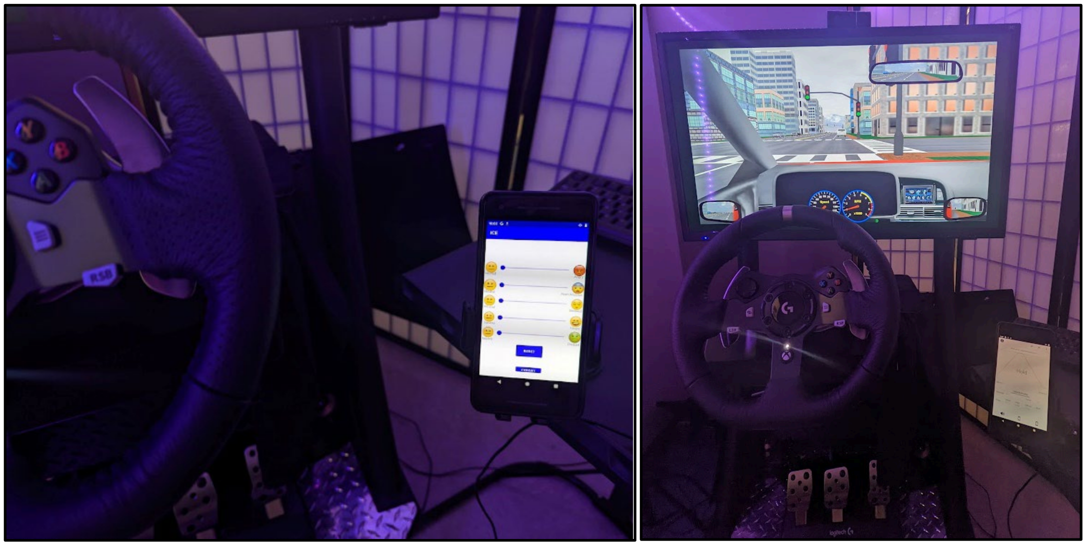

Figure 4. Photos of driver setup shown with ICE integrated into the environment (left) and with the VERT (right).

In a previous study (Susindar et al., 2022), the researchers described the conception and development of an iconic emotion assessment tool (ICE) that was designed with the intention of integrating it into the driving environment and making it easier for participants to record their emotional states. This tool was finessed for this study, and ICE was presented on a mobile device that can be mounted in the same manner as on regular vehicles. Each participant was allowed to place the mount where it was familiar and comfortable for them.

Driving Performance and Safety Assessment

The driving scenarios were constructed in STISIM Drive, a medium-fidelity, stationary desktop driving simulator displayed on a 30-inch screen. Drivers used a Logitech G27 force-feedback steering wheel and floor-mounted pedals to control the vehicle.

The scenario was designed to assess behaviors commonly associated with aggressive driving such as tailgating, yellow light behavior, and speeding (Fernandes et al., 2007). Two equivalent scenarios were designed to incorporate the same elements and assessments, but they varied in order of assessment as well as some aspects of the driving environment (e.g., buildings and scenery). This was done to ensure that participants did not anticipate what was to come in a second run.

Each scenario had a yellow-light corridor; scenario 1 had 30 consecutive yellow lights, and scenario 2 had 31. The additional yellow light in the second scenario was necessary to incorporate all the assessments in both scenarios. The duration (in seconds) of each yellow light was randomized (between 3 and 7 seconds) based on the speed of the participant's vehicle and their distance from the light. This yellow light corridor was designed to emulate the Balloon Analog Risk Task (BART; Lejuez et al., 2003), which is a standardized task for assessing an individual's risk propensity while being sensitive to emotional loads (Susindar et al., 2020). The scenarios designed also included vehicles pulling out in front of the participant with no warning or indication. Participants could slow down or tailgate and switch lanes. There were also two vehicles that were programmed to emulate aggressive driving by brake-checking and not allowing the participants to pass them.

Dependent Variables

Driving Risk Propensity Metric

A driving risk propensity metric (DRPM) was developed based on the metrics used for risk propensity in the BART as a guide. The DRPM is a factor of the total number of lights (30 or 31), the number of tickets for running red lights, the number of yellow lights that were run through successfully (i.e., no tickets), and the number of stops at lights.

N – Total number of lights based on scenario (30 or 31)
T – Number of tickets given for driving through intersections as the yellow changed to red
S – Number of times participants stopped at a yellow light

$$DRPM = \frac{(TL - T) - S}{TL - T}$$

Time to Collision

Time to collision (TTC), measured in feet per second, is a metric based on the recommended safe traveling distance behind a leading vehicle. This study included 18 leading vehicles designed for this specific purpose. This metric is a factor of speed and the distance from the leading vehicle. The safe traveling distance behind a leading vehicle should be at least 2 seconds (3 seconds is usually recommended). The TTC metric is the minimum distance from the leading vehicle/ the speed at which the vehicle is traveling. The driving scenarios developed for this study had elements intentionally scripted to assess tailgating behavior using TTC. For this study, a TTC greater than 2 seconds was considered a safe following distance. Tailgating with a TTC of fewer than 2 seconds was considered risky behavior, and those over 2 seconds were considered not as risky.

TTC – Time to collision (seconds)
D – Minimum distance from the leading vehicle (feet)
S – Speed at minimum distance (feet/second)

$$TTC = D/S$$

Negative Interactions (Spontaneous Tailgating)

One commonly observed aggressive driving behavior is tailgating. Eighteen of the 46 fellow travelers were scripted to assess the TTC measure. The remaining 28 vehicles were called "unscripted vehicles." The frequency was measured as the percentage of unscripted tailgating instances compared to the total number of unscripted vehicles.

N – Total number of unscripted vehicles
n – Number of tailgating events with unscripted vehicles

F – Frequency of negative interactions

$$F = \left(\frac{n}{N}\right) 100$$

Workload

Driver workload was assessed using a computerized NASA Task Load Index (NASA-TLX) survey, which is a measure of perceived workload (Nygren, 1991). A weighted workload (assigning weights to participants' choices), based on responses from the NASA-TLX, was used as the metric for workload.

Procedure

Participants were divided into four groups with two trials that balanced order of emotional context and ERT intervention. Each participant first provided their consent, filled out some background questionnaires, and settled into the driving simulation for two practice runs. They were shown seat adjustment levers and were asked to adjust the seat to their preference. After practice 1, each participant was shown the metrics that would be used to determine their performance on the driving task.

Trial instructions, listed below, were explained during the practice drive and reiterated before every driving trial.

- Reach the end of the scenario as quickly as you can without breaking laws and/or getting caught,
- You cannot turn, but you are welcome to change lanes,
- You must wear the seatbelt (particularly for participants in the SERT group), and
- Your performance on this task will determine your compensation.

After the two practice drives, participants were instructed to listen to nature sounds (johnnielawson, 2017) while following cues on a mobile application to engage in paced deep breathing for 5 minutes. This deep breathing interlude was intended to minimize the influences from previously elicited emotional states and bring participants to a calm or relaxed state. Following this, participants completed the survey to record their emotional states on the ICE tool.

In trial 1, each participant engaged with the emotional stimuli corresponding to either emotion (anger or happiness) depending on the trial order assigned to them. They were then instructed to complete the first driving scenario (scenario 1; rules were reiterated), and their responses on the ICE app were collected immediately before and immediately after each drive. If the participant belonged to an intervention group, the intervention was introduced during the driving trials. After the first driving trial, they were instructed to fill out a computerized NASA-TLX for workload assessment, which marked the end of trial 1. Each participant was then asked to engage in the deep breathing activity for 5 minutes before proceeding to trial 2, which was similar to trial 1, with two differences: this time, the other emotional stimuli were presented (i.e., if trial 1 was anger, trial 2 was happiness), and the driving track was set to the second scenario. The study was complete after the participant completed the second NASA-TLX.

Data Analysis

All the data for each metric were first tested for normality using the Shapiro-Wilk test. If the distribution could be considered normal, parametric tests such as analysis of variance were used with Tukey's honestly significant difference post hoc tests to compare differences among means for significant factors. If the distribution was not normal, non-parametric tests such as Kruskal-Wallis were used, and Pairwise-Wilcox post hoc tests were used to analyze differences among the means. In some cases where some of the data fell outside the acceptable range for outliers (determined depending on normality of distribution), outliers were removed from the dataset. In cases where removing outliers would be detrimental to the size and associated statistical validity, only the values that lay outside the 5% to 95% intervals were substituted with less extreme values. Data from participants who did not follow the experimenter's instructions were removed.

Results

Forty-six adults (Male $N = 29$; Female $N = 17$) between the ages of 18 and 80 (Mean = 25.8, med = 24, SD = 10.37) with a range of driving experience (1–46 years; Mean = 7.35, med = 3.5, SD = 10.76) volunteered to participate in this study. Participants were divided into four groups: group 1 received no ERT (NERT), group 2 received the VERT intervention, and those in groups 3 and 4 received AERT and SERT interventions.

Driving Safety and Performance

Analysis was conducted to compare the effect of ERTs on driving performance and safety metrics, DRPM, TTC, and workload metrics for the four ERT conditions for each target emotion.

DRPM

There was a significant effect of ERTs on the DRPM at the $p < .05$ level among the four conditions [$F(3, 25) = 4.295$, $p = 0.01$] for anger (Figure 5). DRPM with no intervention (NERT) was significantly higher than with VERT ($p = 0.02$) and SERT ($p = 0.03$). Descriptive statistics of this comparison appear in Table 1.

Table 1. Descriptive Statistics of DRPM in Each of the ERTs in the Anger Condition

ERTs	Mean	Standard Deviation
NERT	0.56	0.03
VERT	0.46	0.08
AERT	0.47	0.08
SERT	0.43	0.06

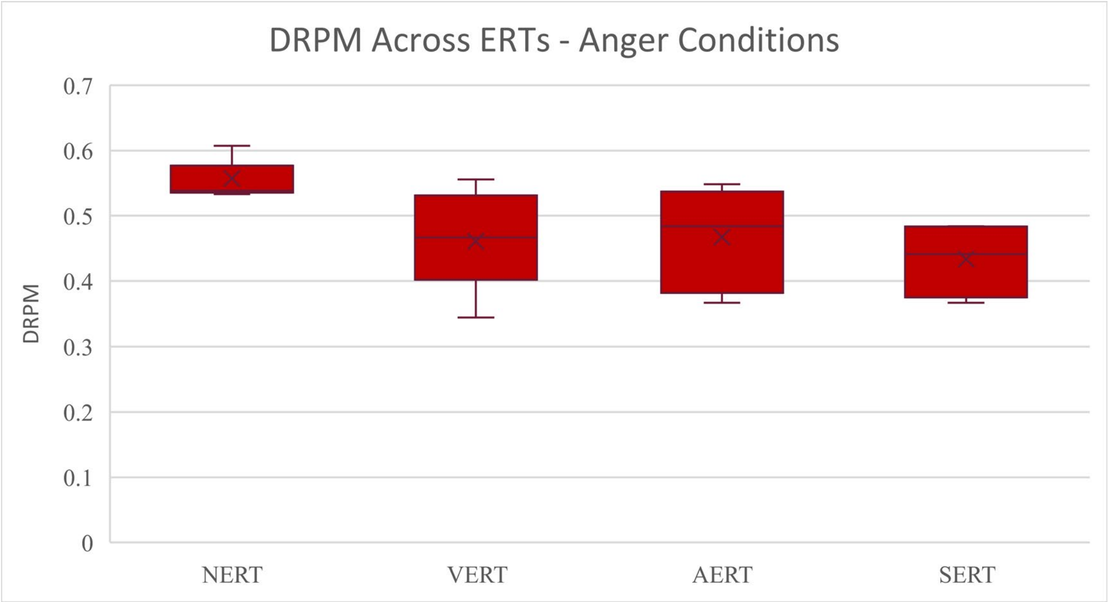

Figure 5. Boxplots showing distribution and means of the DRPM for each ERT group in the anger condition.

There was a significant effect of ERTs on the DRPM at the $p < .005$ level among the four conditions [$F(3, 20) = 5.958$, $p = 0.004$] for happiness as well (Figure 6). DRPM with SERT was significantly higher than with VERT ($p = 0.01$) and AERT ($p = 0.01$). Descriptive statistics of this comparison appear in Table 2.

Table 2. Descriptive Statistics of DRPM in Each of the ERTs in the Happiness Condition

ERTs	Mean	Standard Deviation
NERT	0.47	0.06
VERT	0.38	0.04
AERT	0.36	0.08
SERT	0.52	0.11

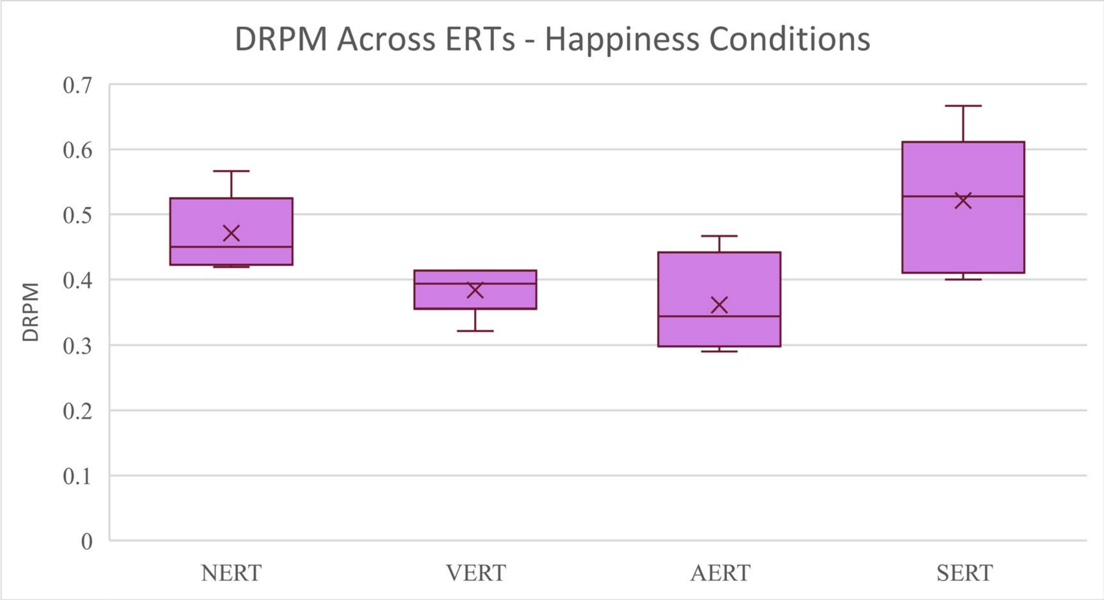

Figure 6. Boxplots showing distribution and means of the DRPM for each ERT group in the happiness condition.

TTC

There were significant effects of ERTs on TTC in the anger condition: $F(3, 47) = 4.32$, $p = 0.009$ (Table 3, Figure 7). The TTC with SERT (M = 7.32 sec) was significantly longer compared to AERT (M = 2.15 sec), $p = 0.004$. There were no significant effects in the happiness conditions: $F(3, 49) = 1.86$, $p = 0.15$ (Table 4).

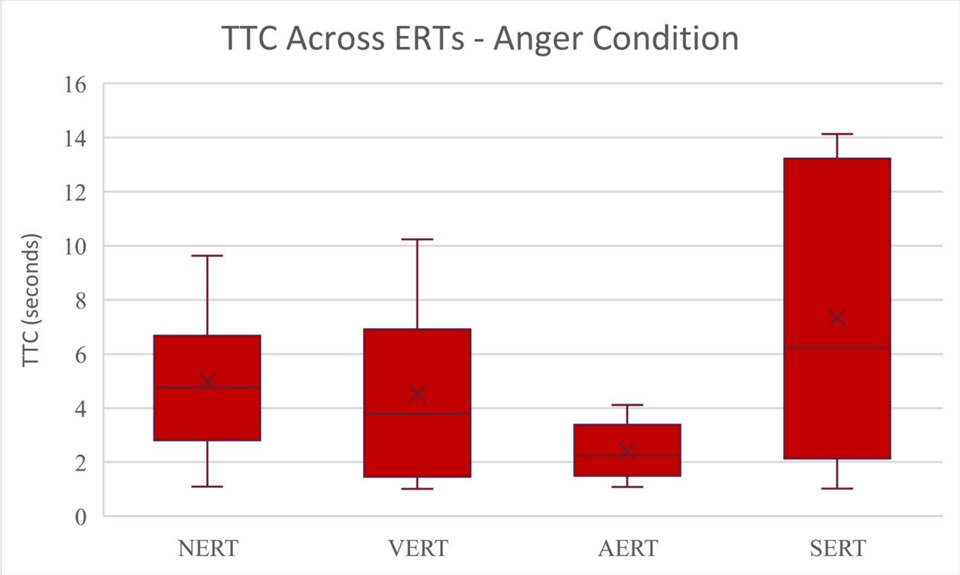

Figure 7. Boxplots showing distribution and means of the TTC for each ERT group in the anger condition.

Table 3. Descriptive Statistics of TTC (seconds) Associated with Each ERT in the Anger Conditions

ERTs	Mean	Standard Deviation
NERT	3.81	1.65
VERT	3.63	2.48
AERT	2.15	1.10
SERT	7.32	5.29

Table 4. Descriptive Statistics of TTC (seconds) Associated with Each ERT in the Happiness Conditions

ERTs	Mean	Standard Deviation
NERT	4.03	2.64
VERT	5.36	3.87
AERT	6.58	5.01
SERT	4.99	3.42

Negative Interactions (Spontaneous Tailgating)

Use of ERTs showed that without intervention (NERT), interactions classified as negative or aggressive were higher by about 11% on average compared to using any of the ERTs in the anger conditions (Figure 8). Similarly, the instances of such behavior were about 13% higher without interventions (NERT) in the happiness conditions (Figure 9).

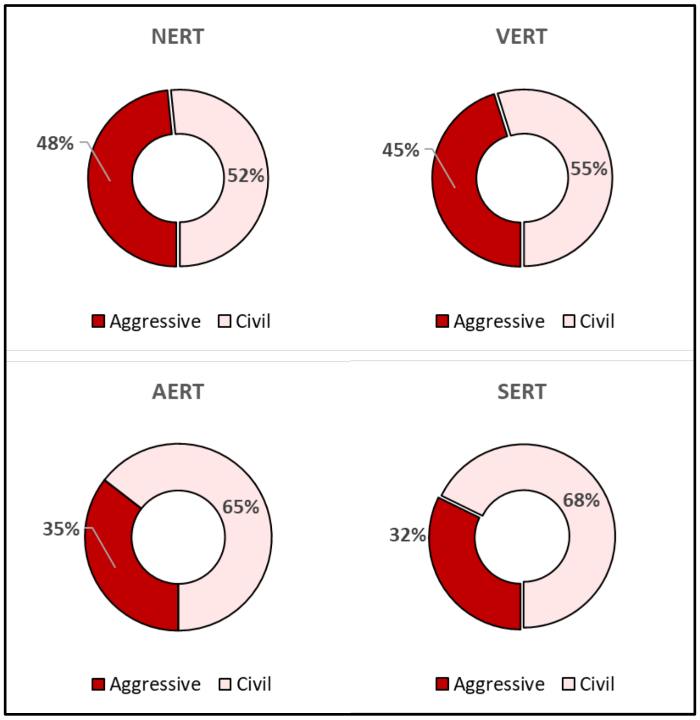

Figure 8. Donut charts representing the relative frequency of aggressive interactions and civil interactions in the anger condition.

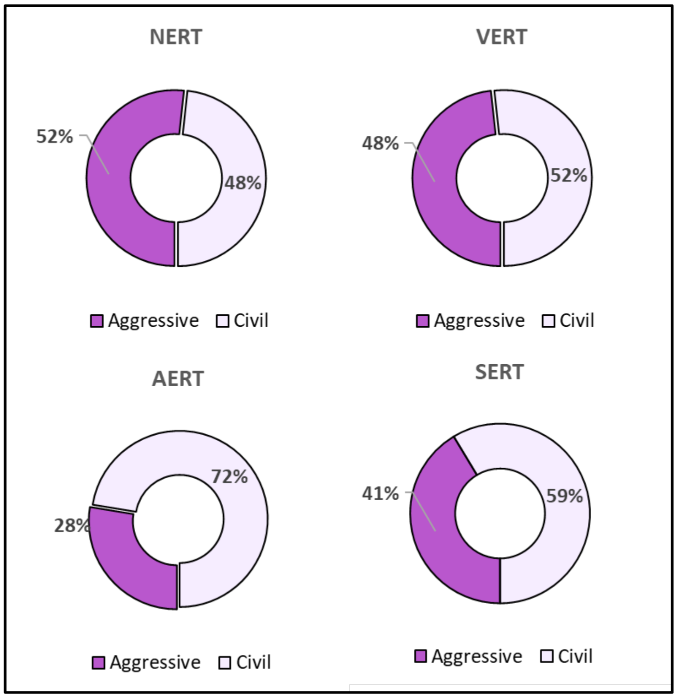

Figure 9. Donut charts representing the relative frequency of aggressive interactions and civil interactions in the happiness condition.

Workload

There was a significant effect of ERTs on weighted workload in the anger condition at the $p < .05$ level among the four conditions [$F(3, 18) = 4.258$, $p = 0.014$] (Figure 10). Perceived workload was significantly higher without intervention (NERT) compared to AERT ($p = 0.02$) and SERT ($p = 0.02$). The descriptive statistics are shown in Table 5.

There were no significant effects on workload in the happiness conditions: $F(3, 21) = 0.52$, $p = 0.67$ (Table 6).

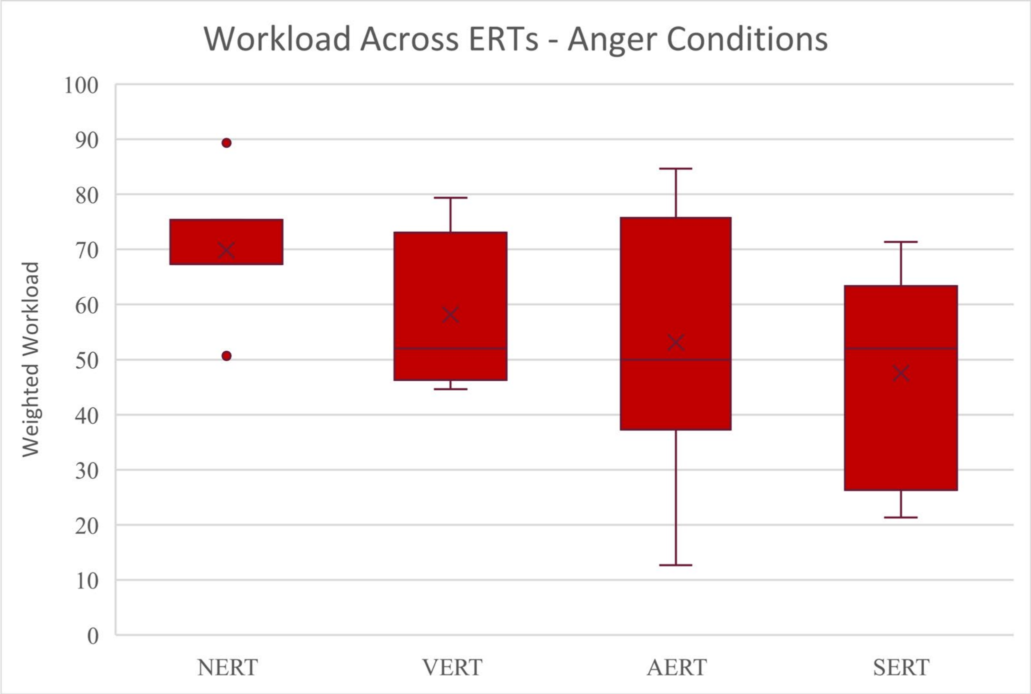

Figure 10. Boxplots showing distribution and means of workload for each ERT group in the anger condition.

Table 5. Descriptive Statistics of Workload Data Associated with Each ERT in the Anger Conditions

ERTs	Mean	Standard Deviation
NERT	73.00	8.62
VERT	58.13	14.53
AERT	45.87	8.72
SERT	47.56	19.59

Table 6. Descriptive Statistics of Workload Data Associated with Each ERT in the Happiness Conditions

ERTs	Mean	Standard Deviation
NERT	49.33	8.24
VERT	55.33	12.19
AERT	48.29	19.70
SERT	52.30	26.19

Discussion

Driving under elevated emotional loads can influence risk-taking and human decision-making behaviors in ways that may be detrimental to system safety and performance. One of the more problematic elevated emotional states in the driving environment is anger, which is a gateway emotion to “rage.” Angry individuals are likely to be more risk accepting and indulge in risky driving behaviors. The same is true for driving under the influence of happiness. Anger and happiness have similar effects on decision-making and are both problematic at elevated states. This study explores the use of interventions, called ERTs, to regulate these elevated emotional states.

ERTs that require minimum cognitive engagement were tested in a simulated driving environment (with angry and happy drivers) and were assessed for their impact on driving performance and safety. The three ERTs in this study utilized different sensory channels—visual (VERT), auditory (AERT), and scent-based olfactory (SERT). The assessment included comparisons with a control group where emotional drivers were not presented with any interventions (NERT).

Driving performance and safety were assessed based on driver risk-taking behaviors and experienced workload. A DRPM was developed (as a factor of total number of yellow lights, the number of stops at yellow lights, and the number of tickets received for running red lights) to assess risk-taking behavior. Tailgating behaviors were assessed using a TTC metric, and workload was evaluated based on the weighted scores obtained from the NASA-TLX.

Anger

Use of ERT showed significant reduction in DRPM compared to no intervention, suggesting that even a visual intervention that competes for resources with the primary driving task may be effective in reducing an angry driver's propensity for risk. Results suggest that the ERTs, irrespective of sensory channel, may be effective for reducing risk propensity.

There was no significant increase in TTC among the three ERTs or compared to no intervention. This could have relevance to the punitive nature of anger and the outward expression of the emotion, including projection of blame (Keltner et al., 1993). However, the percentage of negative or aggressive driving behaviors toward other road users were reduced with the use of ERTs.

Most interestingly, perceived workload was significantly reduced with the use of a visual ERT compared to experiencing anger while driving without any regulation intervention despite the conflict of competing visual resources. This suggests that not only could the experience of anger while driving impose additional workload, but the imposed workload may also be greater than that imposed by performing a secondary visual task. This could imply that the experience of anger is a compelling internal distraction that could be as detrimental to system safety and performance as performing an externally distracting task such as texting while driving.

Happiness

Using the visual or auditory ERT showed significant reduction in DRPM compared to no intervention for regulating an elevated emotional state of happiness. The highlight of the results for the happiness condition was that using the olfactory intervention resulted in DRPM being almost equivalent to experiencing happiness with no intervention. This could be due to the obvious perceivability of the visual and auditory cues and the lack thereof in the olfactory intervention, or due to the subconscious lack of motivation to reduce or contain the experience of the pleasant and positive emotion of happiness. It could be that the perceivability of the cue aids in conveying the intention of the interventions at a conscious or subconscious level, thereby obtaining the driver's buy-in to regulate their emotion. Conversely, the experience of anger is considered unpleasant and may be a motivator for individuals to "stop experiencing" it. This might be a powerful motivation for individuals to consciously or subconsciously engage in emotion regulation.

Another possibility is that the scent of lavender enhances the experience of happiness instead of having the desired calming effect. In this case, the effects on anger can be explained by the ERT that involves countering one emotion with another, in this case, unpleasant negative emotion with a positive, pleasant emotion ("dual-emotion" solution; Lerner et al., 2015).

Results showed no significant differences in TTC among the interventions in tailgating behavior in the happiness conditions. However, the percentage of negative or aggressive driving behaviors toward other road users were reduced with the use of ERTs.

The influence of the three ERTs on perceived workload in the happiness condition did not reveal any significant effects. However, the high variance in the reported workloads suggests the need for a larger study to discern any effects of ERTs on workload. Table 7 shows a summary with interpretations of results from this study.

Table 7. Summary of Recommendations Based on Findings (Ranked)

	Anger				Happiness			
	NERT	**VERT**	**AERT**	**SERT**	**NERT**	**VERT**	**AERT**	**SERT**
DRPM	NR	1	-	-	-	3	3	NR
TTC	-	-	NR	2	-	-	-	-
Negative Interactions	NR	3	2	1	NR	3	1	2
Workload	NR	-	2	2	N/A	N/A	N/A	N/A

NR	Not recommended
Ranks – 1, 2, & 3	Shows promise [most (1) to least (3)]

Conclusion and Recommendations

Drivers are often challenged with decision-making in contexts characterized by high risk, ill-structured problems, uncertainty, and limited resources like time, data and information, representative cues, and cognitive resources. In such instances, elevated affective responses can influence critical aspects of decision-making, such as risk propensity, and compromise driving safety and performance. Employing strategies to minimize the influence of such elevated affective states can support driver decision-making and have a positive impact on driving safety and performance. Interventions for elevated emotional states in such contexts need to be effective in regulating these emotional states while imposing minimal demands on the operator's sensory and cognitive resources, which are already engaged in the demanding primary task.

This study evaluated three ERTs of varying levels of cognitive demand and using different sensory channels to support driver decision-making under elevated emotional loads and compared metrics representative of driving performance and safety with a control group of participants who did not receive any intervention to regulate their emotional states.

Results suggest that assisting the human driver in regulating elevated emotional states like anger and happiness could be beneficial to the performance and safety of the system. The use of interventions may reduce the outward expressions of the experience of anger reflected in risky, aggressive driving behaviors. However, the choice of intervention needs to be carefully considered depending on factors like the perceivability of ERT cues, the nature of the emotion based on motivation to regulate the emotion, and any potential cognitive or physical resource conflicts. Overall, the use of emotion regulation interventions showed promising results for the improvement of driving safety and performance. The choice of the intervention medium may depend on metrics such as workload and possibly the nature of the emotional state.

An overarching limitation of this study was that a majority of participants were young drivers between the ages of 18 and 28, which did not represent the general population. The COVID-19 pandemic also contributed to a few limitations. People who have contracted COVID-19 in the past may have a sense of smell that is not as robust as it was before the contraction. Therefore, participants in the olfactory group (SERT) were asked if they "smelled anything particular during their time participating" and were asked to identify the smell if they could. There were no participants who revealed that they have an impaired sense of smell, and most participants were able to identify the scent as being lavender. Finally, the limitations of running studies in simulated environments also apply, and these experiments would benefit from having real-world testing.

Recommendations

Regulating emotions while driving has a positive effect on driving performance and safety and, due to the nature of the task, it could be quite beneficial to consider integrating emotion regulation interventions with vehicle systems. It is possible to introduce auditory interventions that can be masked with vehicle sounds or be hard to perceive even when the driver is listening to music while driving. Additionally, increasing awareness of driving under the influence of emotions and making information on various regulation techniques more accessible could also have positive effects on driving safety and performance.

The work presented here could establish a more systems-oriented basis for both theoretical and application-oriented explorations into the design of interventions to regulate elevated emotions experienced in the driving context. Results from this study can guide the design and selection of interventions to regulate elevated emotions in high-risk contexts like driving. ERTs can be selected based on the nature of the emotional state, available time, workload, effectiveness of the intervention, available sensory channels, attributes of the environment, and the individual (sensory perception). The COVID-19 pandemic introduced an additional factor that can increase the instances of aggressive driving. People infected by COVID-19 have shown symptoms of mood disorders contributing to increased aggression (Heitzman, 2020).

Vehicle manufacturers are integrating more decision support technologies in their vehicles and, due to the dangers associated with road rage, affect regulation in the driving context will inevitably become a consideration for transportation in the future (e.g., Wu et al., 2022). ERTs like the ones used in this study can be supplemented with methods based on "cognitive re-appraisal" used in prior driving research (Harris & Nass, 2011; Jeon et al., 2011) and can increase the chances of successful emotion regulation.

Additional Products

https://safed.vtti.vt.edu/projects/evaluating-emotion-regulation-techniques-for-supporting-driving-safety-and-performance-2/

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