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ORIGINAL PAPER

How do angry drivers respond to emotional music? A comprehensive perspective on assessing emotion

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Abstract

Emotions influence the way drivers process and react to internal or environmental factors, but relatively little research has focused on drivers' emotions. Of many emotional states, anger is considered the most serious threat on the road. Therefore, having an affective intelligent system in the car that can estimate drivers' anger and respond to it appropriately can help drivers adapt to moment-to-moment changes in driving situations. To this end, we integrated behavioral, physiological, and subjective data to monitor drivers' affective states in various driving contexts to address the question: "can self-selected music mitigate the effects of anger on driving performance?" In our experiment, three groups of participants (in total 52) drove using a driving simulator: anger without music, anger with music, and neutral without music. Results showed that angry drivers who did not listen to music had riskier driving behavior than emotion-neutral drivers. Results from heart rate, oxygenation level in prefrontal cortex, and self-report questionnaires showed that music could help angry drivers react at the similar level to emotion-neutral drivers. Regarding personality characteristics, drivers who had anger-expression out style had riskier driving behavior. Divers' workload data showed lower performance and higher effort for angry drivers without music. In conclusion, this study shows that multimodal sensing can be effectively used to holistically assess drivers' emotional states and that music can be used as a possible multimodal strategy to mitigate the anger effects on driving performance as well as drivers' subjective experiences.

Keywords Emotions · Music effects on driving · fNIRS · Heart rate · Driving simulation

1 Introduction

Driving is a complicated task that requires the coordination of visual and sensory-motor skills. Unsafe driving behavior and accidents can happen regardless of the level of drivers' experience. The main cause of the most of these accidents is human error. Emotions influence the way drivers process and react to internal or environmental factors. Specifically, anger elicited either from traffic or personal issues, is a serious threat on the road. Therefore, having an affective intelligent system in the car that can estimate drivers' anger and respond to it appropriately can help drivers adapt to moment-to-moment changes in driving situations. To this end, the present study uses an integrated approach to monitoring drivers' affective states in various driving contexts to address the question: "How do angry drivers respond to self-selected music?"

Three sources of information (behavioral, physiological, and subjective data) were considered to find the influence of music on angry drivers' errors, while driving in low, medium, and high traffic conditions. The results of this experiment showed the type of errors angry drivers made and the differences among angry drivers' behavior when they listened to music and did not. This research showed the benefits of music as a possible strategy to help angry drivers. In addition, important patterns were uncovered relating to assessing driver anger for possible affective intelligent systems in cars.

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2 Background on music, driving, and emotions

In total, 106,727 fatal crashes during the years 2003 to 2007 involved at least one driver who committed a potentially-aggressive action [1]. Results of [2] showed that more than 78% of drivers, mostly ages 25–39, reported having engaged in at least one aggressive driving behaviors (e.g., tailgating, yelling at other drivers, blocking another driver from changing lane) in 2014. Another surprising result in this study was that around 5.7 million drivers in the US intentionally bumped or rammed another vehicle in 2014. Moreover, male drivers committed more aggressive driving behaviors than female drivers.

Recently, emotions have been considered as a critical factor of driver distraction in driving safety research. Emotions have a major impact on performance, regardless of whether they are processed independently of the cognitive process or not [3, 4]. Emotional drivers may fail to look at the right spot at the right time since their attentional resources are occupied by the demands of emotions [5]. Among all types of emotions, anger is relatively a common emotion while driving [6]. It is widely accepted in driving research that angry drivers make more driving errors than non-angry drivers [7–10].

Anger is one of the eight basic emotions [11] which like other emotions, consists of distinct components that vary in different situations. The components include patterns of peripheral physiological responses, brain activation, physical sensation, subjective feelings and experiences, cognition, and action tendencies [7]. The operational definition of anger refers to a negatively felt state associated with cognitive distortions and physiological changes in response to a negative stimulus that may result in maladaptive patterns of behavior [12]. Anger has been associated with a sense that one has been treated unfairly by another entity paired with a certainty of unfairness [13, 14]. Feeling angry usually creates a kind of belief that another person is responsible for the negative event and an expectation that the self has the ability to overcome the situation [15].

There is a great deal of evidence that suggests anger has physiological effects. Scherer and Wallbott [16] studied bodily changes of 2921 samples from 37 countries during anger and found that anger was characterized by rapid heart rate, tension, fast breathing and feeling hot.

Some studies found that the presence of music while completing a task may add cognitive load due to additional irrelevant stimuli and contribute to cognitive overload, especially when there are not enough cognitive resources to attend to all the demands of the task [17]. It is also found that listening to music does not negatively influence driving performance [18] but can even facilitate safer driving [19]. A survey research project showed that listening to music is not correlated with drivers' self-reported crashes [20]. Regarding the influential characteristics of music, [21] showed that 83% of drivers had less stress while driving with music.

It seems that the potential benefits of listening to music while driving are moderated by mental workload levels. If a driving task is very demanding, a secondary task (in this case, listening to music) may deteriorate driving performance. However, in an unchallenging driving environment, a secondary task may not influence task performance at all or even enhance driving performance in some conditions. Data suggest that the effect of music on driving is partly determined by the primary task difficulty [18, 22, 23] and music is just one of many potential strategies to regulate the arousal levels of drivers [23].

According to multiple resources theory [24], each task has a vector that shows the number and qualitative level of the resources. Assuming that driving requires visual, spatial, and manual resources, the amount of load within each resource depends on the task demands. For example, in an icy road manual resource demands will increase versus a foggy road that requires visual attention. Therefore, this model assesses the overall performance by considering the extent to which the total demand on several tasks is, or whether the tasks compete for overlapping resources. Based on this theory, if two tasks have equal priority, performance on both tasks will be degraded equally [24]. This theory is helpful to understand peoples' performance in a multitasking situation like driving.

Ünal et al. [22] discussed that drivers' performance may deteriorate by the emotion independently or by influencing on cognitive process due to less available resources for driving. Research on the effects of emotions in general, and anger specifically, suggests that emotional states have impacts on both what and how people think. Lerner and Tiedens [15] in their Appraisal-Tendency Framework (ATF) distinguished the effects of specific emotions on judgment and decision making. The ATF assumes that specific emotions create specific cognitive properties that may represent at the biological and behavioral level. Their research showed that angry people tend to be more optimistic when negative outcomes are de-emphasized, and they also blame other individuals more for negative outcomes [15]. Thus, they may not be careful on the road. This offers a potential explanation for the driving errors of angry and aggressive drivers.

The gaps and contradictory results of previous studies show that the effects of music on the primary task, in this case driving, depend on the type of music and the demands of the primary task e.g., traffic condition. If the driving situation is not demanding, usually music not only distracts drivers [e.g. 19], but also in some situations, it facilitates driving performance [e.g. 20]. In this situation, music can be interpreted as a “positive” distractor in that it occupies a small portion of cognitive resources all of which were busy with the emotional information. This notion is close to the third stage of Gorss’ emotion regulation procedure [25], which is called attentional deployment [26]. Likewise, [27] showed that simple speech-based interventions (as attention deployment) helped angry drivers successfully divert their attention from anger to the driving environment. Jeon [28] discussed the effect of arousal on performance. He explained that with increased arousal, the number of cues that can be processed by the individual will decrease. Therefore, the unnecessary information will be ignored by the person; however, this filtering procedure does not guarantee that the relevant information will not be eliminated. He added that optimal arousal will vary from task to task. Cue-utilization theory (1959) [29] has explained the inverted U-shape relationship between emotional arousal and performance. This theory assumes that at the medium level of emotional arousal, performance is optimal, and individuals can process a large number of cues. If the arousal increases more than the optimal level, it negatively impacts individuals’ ability to process the number of cues.

However, other than the circumplex model of emotion, some studies explain music effects based on theories of discrete emotions, e.g., appraisal theory. According to the appraisal theory of emotion, emotions arise from the perceptions of environmental changes and circumstances. This perception is influenced by personality characteristics, physiology, culture, and current goals. The construction of the evaluation i.e., mental model (based on novelty, valence, certainty, goal conduciveness, agency, and control) specifies the types of emotion that a person feels [30]. Therefore, if we try to change angry drivers’ mental model (e.g., others’ responsibility for the situation) by specific types of music, we might mediate or regulate drivers’ anger or other emotions [31].

It is important to consider that a number of music profiles, such as genres, instruments, musical elements, and familiarity may impact drivers in different ways [27]. For example, [32] suggested that processing unfamiliar melodies is much more demanding than familiar melodies. This notion can explain some of the results of studies that used either self-selected or experimenter-selected music. Overall, listening to certain music can reduce driving performance degradation associated with negative emotion by redirecting drivers’ attention [33]. In other words, music may only use residual resources beyond what is required for driving in a low-demanding road situation. In the applied context, the results from models of emotion and task sharing are valuable for their ability to predict performances in multi-tasking environments. Since our experiment is a multitasking situation (driving accompanied by music) in different driving situations (difficulty level), multiple resources theory will explain the overall drivers’ performance based on the extent to which the total demand on several tasks is and how much the tasks compete for overlapping resources.

Scherer [7] and Wallbott and Scherer [34] defines emotion as “an episode of interrelated, synchronized changes in the states of all or most of the five organismic subsystems in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism” (p. 697). The components of an emotion represent the five subsystems that have roles in creating an emotion and the related process over time. In this study, we considered the most important emotional components through different layers of data (self-report assessments, behavioral observations, and physiological responses). This holistic approach on assessing emotion in interaction with the environment (traffic demands) and drivers’ personality characteristics is unique and aims to fill up the gap and answer the contradictory results of the previous studies in which sometimes, self-selected music might emotionally engage drivers and so, distracted them from attending to the road; othertimes, music helped drivers reduce boredom and stress.

3 Theories of measuring emotion

Scherer [7] and Wallbott and Scherer [34] stated that since there is no single standard method for measuring emotion, comprehensive assessments of all or most of the changes are required to measure emotion. Based on Scherer’s componential theory of emotion, to assess emotion, we need to measure (1) appraisal processes, (2) the response patterns generated in the neuroendocrine, autonomic, and somatic nervous systems, (3) the motivational changes produced by the appraisal results, (4) the patterns of facial and vocal expression as well as body movements, and (5) the nature of the subjectively experienced feeling state that reflects all of these component changes. To assess drivers’ anger in this study, most of these components were considered. For the cognitive and motivational component and subjective feeling, self-report questionnaires were used (subjective data). Heart rate measurements and fNIRS data were analyzed for the neurophysiological component (physiological data). Regarding the motor expression component, drivers’ driving performance was observed on the driving simulator (behavioral data).

In an emotional situation, all the above components work together. After processing information, autonomic nervous system (ANS) distributes some specific signal from central nervous system (CNS) to the end organs to achieve an optimal state of homeostasis. If an action is necessary to happen, the endocrine system and ANS will support the motor system. All the above systems (motor and endocrine as well as autonomic homeostatic regulations) are under the control of the forebrain and they are integrated with representations of the perceptual world. The CNS signals can be modified within the autonomic ganglia, which allow for self-regulation at various system levels [14].

Likewise, Thayer et al. [35] also considered emotion as a multidimensional process. In their "super system", they introduced autonomic nervous system (ANS) and heart rate variability (HRV) as two important systems that interact with each other to integrate physiological responses in the context of emotion with the consideration of environmental demands and the individuals' goals. In the next section we explain more about HRV and hemodynamic changes of prefrontal cortex (PFC) which are important in most of emotional changes.

3.1 Heart rate variability (HRV) and methods to measure HRV

HRV refers to the variance between heart beats which varies from person to person and depending on the situation they are experiencing [36]. "Normal-to-normal" (NN) intervals is another name for HRV since HRV means the temporal distance between R spikes generated by sinoatrial depolarizations [37]. To measure HRV, we calculated the standard deviation of N–N intervals (another way of saying R–R intervals) grabbed from the time domain strategy under statistical class. This strategy represents the total variability of HR in a period which can be linked to the emotional states. For example, high frequency HRV represents parasympathetic influences and lower frequency (below about .15 Hz) shows a mixture of sympathetic and parasympathetic autonomic influences [35].

3.2 Hemodynamic changes of pre-frontal cortex

In this study, fNIRS is used to monitor PFC, which is an important region in emotional processing [38]. The PFC role in emotion has been the topic of many studies. Some results showed a significant PFC lateralization effect to emotional stimuli with different valance (positive and negative) [39].

To activate any region in brain and produce action potentials in neurons, blood flow should provide oxygen and other necessary substances. Therefore, changes in blood oxygenation can be an index of brain activity. During activation, metabolic rate of oxygen increases. As much as neurons consume more oxygen, a decrease in tissue oxygenation will happen. If that part of the brain is still activated with a lasting stimulus, an increment in blood flow keeps glucose and oxygen constant in neurons (Fig. 1). Therefore, there are two variables that represent the above procedure:

A. **OxyHb**: Oxyhemoglobin (also O2Hb): when hemoglobin transports oxygen
B. **DeoxyHb:** Deoxyhemoglobin (also HHb): when hemoglobin releases oxygen by increment in oxygen consumption

4 Contributions to in-vehicle multimodal systems

Our contributions to multimodality are two-fold. On one hand, we used a combination of multimodal affect detection techniques, including self-report instruments, physiological sensing, neuroimaging, and expert observer evaluation. To understand the effects of emotions and music on drivers' affective states, we needed this comprehensive approach. We have also tried to develop an affect detection system using facial expression recognition and speech analysis [38]. We are aware of that it is not always working like "the more, the better". However, literature consistently shows that multimodal sensing is required to effectively and efficiently estimate users' affective states [40]. Thus, we wanted to test and try out each method and different combinations, so we can identify the optimal approach.

On the other hand, we hope to design and develop multimodal intervention strategies for emotional drivers. Traditional approaches focused on either passive methods (e.g., temporarily prevent incoming calls) or updating graphical user interfaces (e.g., changing font size, layout, color, etc. [41]). We have tried to use auditory modality in addition to these strategies since auditory modality does not compete with a primary driving task, which heavily depends on visuo-motor modalities (e.g., Multiple Resources Theory, [42]). In addition to our previous attempt to use speech-based systems [11], the present paper tries to use non-speech sounds for mitigating emotional effects on driving.

5 Experiment

In this experiment, differences between angry and non-angry drivers' driving performance were investigated. Besides their driving errors, their physiological responses were evaluated based on their anger response style and other

Fig. 1 A short story of activation in cerebral region

subjective variables such as workload were compared among the groups. Self-selected music pieces were used to identify how much music can change emotional reactions, driving behavior, and perceived experience. Other driver characteristics, including participants' answers to driving anger scale, their driving experiences, and their anger expression style were also investigated. Anger expression style refers to the way that people convey their emotion. Wickens and McCarley [43] classified individuals based on the way that they express their emotion. He suggested that people with anger-expression-out response style are in the habit of expressing their anger outwardly which may lead to some types of aggressive actions either behaviorally or verbally [44]. Therefore, based on Spielberger's notion, people with anger-expression-out response style may make more errors than others. Observation of drivers in naturalistic or simulated driving environment showed that high-trait and aggressive drivers make more errors [45, 46].

5.1 Hypothesises

This is a list of the hypotheses that will be tested in this experiment:

Hypothesis 1 Angry drivers will show worse driving performance than non-angry drivers.

Results of previous studies indicate that angry drivers make more errors than non-angry drivers (e.g. [9, 11]).

Hypothesis 2 Angry drivers in the music group will show better driving performance than angry drivers in the no music group.

Hypothesis 3 Angry drivers in the music group will report less anger after the experiment than those in the no music group.

Hypothesis 4 Angry drivers in the music group will show a different pattern in their physiological data than those in the no music group.

Hypothesis 5 Drivers with a higher score in anger-expression-out subscale and driving anger scale will show worse driving performance (behavioral level) than other drivers.

6 Methods

Before conducting the experiment, we obtained an approval for the study protocol from the Michigan Technological University Institutional Review Board. There was no more than minimal risk associated with participating in this study.

6.1 Participants

Fifty-two participants (male = 43, female = 9, mean age = 21.82, SD of age = 2.42) participated in this study for partial research credits in the introductory psychology class. The disproportion of genders is due to the population of undergraduate classes at Michigan Tech. The entire experiment took one hour.

6.2 Apparatus

6.2.1 Driving simulator

The driving simulator consists of SimuRide software running on a Dell Optiplex 960 using Windows 7 operating system. The monitor is a 39" Samsung LED TV placed on a desk in front of the participant. SimuRide's driving simulator sounds are from a speaker behind the monitor averaging around 75 decibels from 2 feet away from the participant. A Thrustmaster universal USB steering wheel and gas/brake pedals were used to better simulate real world driving (Fig. 2).

6.2.2 Electrocardiogram (ECG)

To measure heart rate and heart rate variability, we used a polar H7 heart rate sensor. It is a belt that can be connected to HRV Logger app via Bluetooth and transmit live heart data (75 Hz) to a smartphone.

Fig. 2 Participants anger score before and after emotion induction and before leaving the lab in the groups on a Likert scale from 1 (not at all) to 7 (very intense). Error bars represent standard errors in all graphs

6.2.3 Functional near-infrared spectroscopy (fNIRS)

Hamamatsu NIRO-200NX is a non-invasive, lightweight tool which is designed to monitor changes in concentration of oxygenated and deoxygenated hemoglobin and the degree of oxygenation of human tissues using optical methods. It has one detection and one emission probes in each channel (two left, two right) with a hairband. The hemodynamic changes can be seen in its monitor (Fig. 2).

6.3 Materials

6.3.1 Differential emotions scale (DES)

To assess discrete emotional dimensions, we used self-report scales of discrete emotional states. This questionnaire contained 16 items and participants rated each item using a 7-point Likert-type scale from 1 (not at all) to 7 (very much) [47].

6.3.2 Cognitive-affective response test-music (CART-M)

Bartel [48] claimed that cognitive and affective phases can be distinguished on the basis of two dimensions: formal-intellectual and emotional-expressive. This questionnaire consists of nine semantic scales for each of formal-intellectual and emotional-expressive response dimensions.

6.3.3 Driving anger scale

This self-report questionnaire measures driving anger in several hypothetical anger-provoking driving scenarios. We used the 14-item short form that is highly correlated with scores on the long form [49].

6.3.4 State-trait anger expression inventory-2 (STAXI-2)

STAXI-2 is a self-report questionnaire consists of 57 items to assess 5 subscales: State Anger (S-Ang), Trait Anger (T-Ang), Anger Expression-Out, Anger Expression-in and Anger Control. State Anger refers to the intensity of the individual's angry feelings. Trait Anger evaluates a person's general predisposition to become angry. The Anger Expression-Out scale describes the extent to which a person expresses her emotional experience of anger in an outwardly negative and poorly controlled manner. People with Anger Expression-in hold things in or suppress anger when they are angry. Anger Control-Out involves the expenditure of energy to monitor and control the physical or verbal expressions of anger. Anger Control-In measures how often people attempt to relax, calm down, and reduce angry feelings before they get out of control. The AX Index provides an overall estimate of the person's tendencies to express anger either outwardly toward other people, or inwardly toward herself.

6.4 Design and procedure

We had three between-subjects conditions: angry drivers who drove with self-selected music (Anger with music), angry drivers who drove without music (Anger without music), and neutral drivers who drove without music (Neutral without music). After completing the consent procedure, we asked participants to rate their current emotional state using the Differential Emotions Scale (DES) and fill out the state-trait anger expression inventory (STAXI-2). Before driving in the experimental scenario, participants practiced for 5 min in a different scenario. This helped them feel comfortable and control over the simulator. This practice session could also change their perception of music. The previous study showed that when people are completing a novel task, they may not perceive music simultaneously as much [22]. The practice session also allowed us to screen participants' sensitivity to simulation sickness by comparing the scores of simulation sickness test before and after the practice session even though there has been no simulation sickness reported with this low-fidelity simulator. After the practice session, in the Neutral without music group, participants drove with the neutral affective state without listening to music. Participants in the angry conditions spent 12 min writing about an angry experience they could vividly remember (e.g., [38]). This method consistently shows its effectiveness in previous driving studies [50]. Then, to assess different aspects of the emotional event, they filled out the Answer Alternative questionnaire [34] for 5 min. After the mood induction procedure, they rated their emotion check survey for the second time. Next, they had 2 min to pick a music piece from YouTube or cellphone playlist. They were asked to pick a song that they want to listen to while they are driving on the simulator. This music was played on repeat from the experimental computer during the whole driving in the experimental scenario. Since the driving session lasted around 15 min, most of the songs were played on repeat for 3 to 4 times. Participants in the Anger without music group did not listen to any music for the drive. Participants were instructed to obey all the traffic rules that they normally do on the road. The driving session lasted approximately 15 min. Driving performance data were collected manually in real-time by a trained experimenter who was present at all times. In this way, the experimenter observed the participants' driving performance and recorded the number of all driving errors. This means that the driving simulator did not record any types of data related to the driving performance. Following the driving portion, participants answered to Cognitive

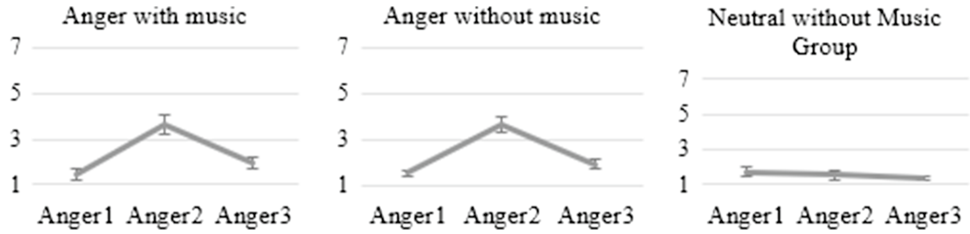


Fig. 3 A participant driving on the driving simulator

Affective Response Test-Music (CART-M), Differential Emotions Scale (DES), DAS, NASA-TLX, and demographic questions.

7 Results

7.1 Subjective results: emotion manipulation check

In this experiment two out of the three groups went through the emotion induction procedure. During the procedure, participants were supposed to remember and write a memory that makes them angry. Participants in Neutral without music group wrote about a normal daily activity to stay neutral. The idea behind this grouping is to see how much angry drivers' behaviors are different from neutral drivers and if music can help angry drivers or not. Then, drivers' emotion was checked via self-report questionnaires three times through the experiment:

- When participants entered the lab (Anger 1)
- After emotion induction procedure (Anger 2)
- At the end of the experiment before they left the lab (Anger 3)

Figure 3 shows the patterns of groups' self-report anger through the experiments. Results of a one-way repeated measures ANOVA showed significant differences in Anger without music group (Wilks' Lambada = .364, $F(2, 15) = 15$, $p = .000$) and Anger with music group (Wilks' Lambada = .364, $F(2, 16) = 21$, $p = .000$) among the three self-report questionnaires. As we expected, participants in the Neutral without music group did not report the same changes.

Several paired samples *t* tests were used to make post hoc comparisons between the reports. Paired samples *t* test indicated that participants in the Anger with and without music groups reported that they are significantly angrier after emotion induction in comparison to the time when they entered the lab and after the experiment (before leaving the lab) (Table 1). Tables 2 and 3 show the t and p values from the *t* tests.

To find in which conditions drivers' anger decreased more, the differences between self-report anger 3 and 2 in Anger with and without music were compared. Results of independent samples *t* test shows that the decrement in participants anger is not different between the groups ($t(16) = -.24$, $p > .05$).

Table 1 Mean of self-report anger in each group

Groups	Anger 1	Anger 2	Anger 3
Neutral without music	1.7	1.52	1.35
Anger with music	1.44	3.66	1.94
Anger without music	1.52	3.64	1.94

Table 2 Paired samples *t* test of self-report anger scores of before and after emotion induction

Groups	t value anger 1, 2	*p* value
Neutral without music	.71	> .05
Anger with music	−5.71	< .05
Anger without music	−5.26	< .05

Table 3 Paired samples *t* test of self-report anger scores of emotion induction and before leaving the lab

Groups	t value anger 2, 3	*p* value
Neutral without music	.67	> .05
Anger with music	6.51	< .05
Anger without music	5.39	< .05

7.2 Physiological data

7.2.1 ECG (HR)

7.2.1.1 Between group comparisons ECG data were analyzed based on two statistical values: mean of heart rate (HR) and standard deviation of heart rate variability (HRV).

ECG (HR): To compare drivers' HR data during the driving sessions, several one-way ANOVAs were performed on drivers' mean of HR. Results show that the mean of HR during the driving sessions are different among the groups ($F(2, 47) = 3.08$, $p = .04$). In other words, angry drivers' HR who did not listened to music ($M = 85.09$, $SD = 9.06$) was

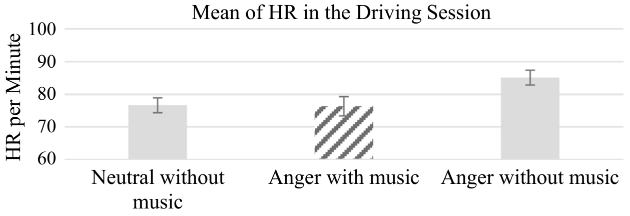


Fig. 4 Mean of drivers' HR during the driving session among the groups

Table 4 Means, standard deviations, and standard errors of HRV in the three groups

Groups	Mean	SD	SE
Neutral without music	59.52	15.11	3.77
Anger with music	59.26	27.83	6.74
Anger without music	58.88	27.16	7.01

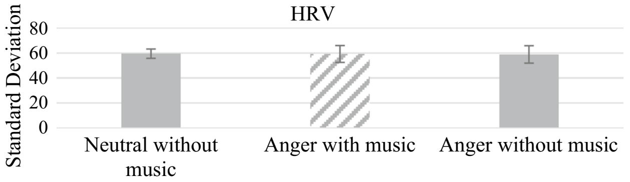


Fig. 5 Standard deviation of drivers' HRV during the driving session among the groups

significantly higher than angry drivers who listened to self-selected music ($M = 76.38$, $SD = 12.22$), and neutral drivers' HR ($M = 76.66$, $SD = 8.99$) (Fig. 4).

This can be related to drivers' anger state (higher arousal) and the role of music. The difference between angry drivers with and without music groups is listening to self-selected music in the music group. Drivers in both groups were angry based on their self-report results. Lower heart rate in the music group can be attributed to the role of music in changing and decreasing angry drivers' arousal level back to the normal or neutral state.

ECG (HRV): Drivers' HRV data during the driving session were compared among the groups (Table 4). Results did not show any differences among the groups ($F(2, 47) = .38$, $p > .05$) (Fig. 5).

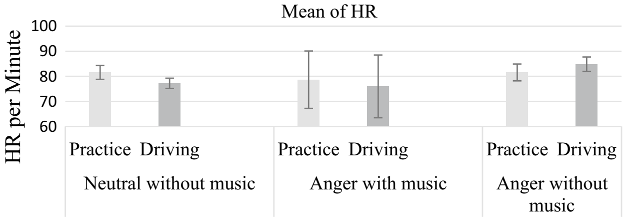


Fig. 6 Mean of HR during different sessions among the groups

7.2.1.2 Within group comparisons When it comes to physiological data, individual differences should be considered. To reduce the influence of individual differences in this between-subjects design experiment, heart rate (Fig. 6) and heart rate variability (Fig. 7) data were analyzed through the different phases (practice and driving). In other words, we compared each person's ECG data when she was in different phases of the experiment. This would give us a better understanding of the changes in each individual during the experiment.

ECG (HR)

Neutral without music group: Paired samples *t* test indicated that mean of HR in driving ($M = 77.23$, $SD = 7.33$) session is significantly lower than practice session ($M = 81.57$, $SD = 9.97$), $t(12) = 3.74$, $p < .05$.

Anger without music group: Paired samples *t* test indicated that mean of HR in driving ($M = 84.82$, $SD = 12.27$) is significantly higher than practice session ($M = 81.58$, $SD = 14.26$), $t(17) = -3.94$, $p < .05$.

Anger with music group: Paired samples *t* test indicated that mean of HR in driving session ($M = 76$, $SD = 12.51$) is not significantly different from the practice session ($M = 78.67$, $SD = 11.46$), $t(15) = 1.5$, $p > .05$.

ECG (HRV)

Neutral without music group: Paired samples *t* test indicated that SD of HRV in driving ($M = 57.76$, $SD = 13.84$) session is not significantly different from practice session ($M = 59.72$, $SD = 20.19$), $t(14) = .66$, $p > .05$.

Anger without music group: Paired samples *t* test indicated that SD of HRV in driving ($M = 73.46$, $SD = 17.74$) is not significantly different from the practice session ($M = 50.48$, $SD = 74.60$), $t(15) = -1.27$, $p > .05$.

Anger with music group: Paired samples *t* test indicated that SD of HRV in driving ($M = 58.84$, $SD = 27.61$) session is not significantly different from the practice session ($M = 66.81$, $SD = 50.58$), $t(14) = .71$, $p > .05$.

7.2.2 fNIRS

Results from fNIRS are based on the oxygenation (O2Hb) of PFC from both hemispheres. Results did not show any patterns regarding deoxygenatin (HHb) and asymmetrical patterns of hemispheres in positive and negative emotions.

7.2.2.1 Between group comparisons Participants' hemodynamic changes of PFC during the driving session were tested with a one-way ANOVA to see if there are any differences among drivers who listened to music and those who did not with different emotional states. Results showed that

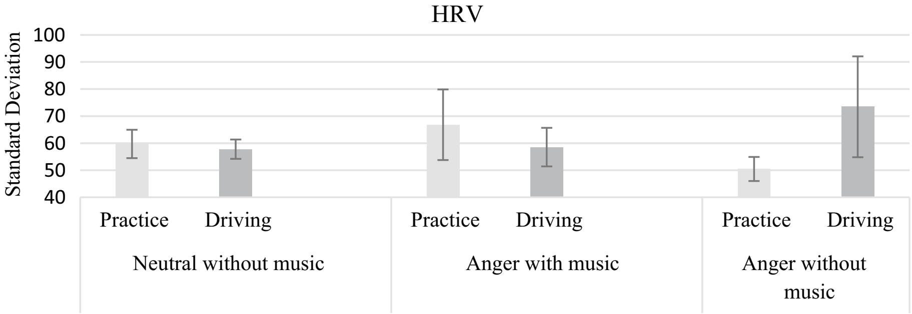


Fig. 7 SD of HRV during practice and driving sessions among the groups

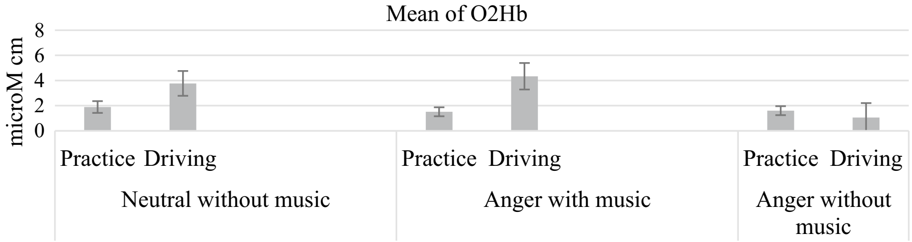


Fig. 8 Mean of oxygenation during practice and driving sessions among the groups

the hemodynamic changes are not significantly different among the groups ($F(2, 44) = 1.39$, $p > .05$).

7.2.2.2 Within group comparisons Like ECG data, fNIRS results might be sensitive to the individual differences. Therefore, we checked the hemodynamic changes of PFC during the phases (practice and driving) for each participant in a group (Fig. 8).

Neutral without music group: Paired samples *t* test indicated that average O2HB (mean-driving = 3.76, mean-practice = 1.89, $t(16) = 2.19$, $p < .05$) significantly increased from practice to the driving session.

Anger without music group: Paired samples *t* test indicated no changes from practice to the driving session ($t(14) = -.43$, $p > .05$).

Anger with music group: Paired samples *t* tests between practice and driving sessions showed that average O2HB (mean-driving = 4.38, mean-practice = 1.51, $t(14) = 3.17$, $p < .05$) significantly increased from practice to driving session.

7.3 Behavioral data: driving errors

Drivers' lane departure, speeding, fuel-efficient driving, number of crashes, passing red-light, and passing stop sign were observed manually by the experimenter. Fuel-efficient driving is the only factor that was different among the groups. A one-way ANOVA was performed on drivers' fuel-efficient driving performance among the groups. Drivers in different groups showed significantly different performance in fuel-efficient driving behavior $F(2, 47) = 3.94$, $p < .05$ (Fig. 9). Post hoc analysis with least significant difference (LSD) shows that angry drivers who did not listen to any music ($M = 210$, $SD = 163.18$) had worse fuel-efficient driving performance than the drivers in the neutral ($M = 96.25$, $SD = 50.44$, $p < .05$) group.

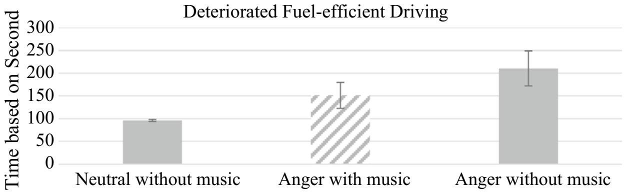


Fig. 9 The total time of deteriorated fuel-efficient driving in different conditions. Angry drivers without music group showed worse fuel-efficient driving performance than the drivers in the neutral without music group

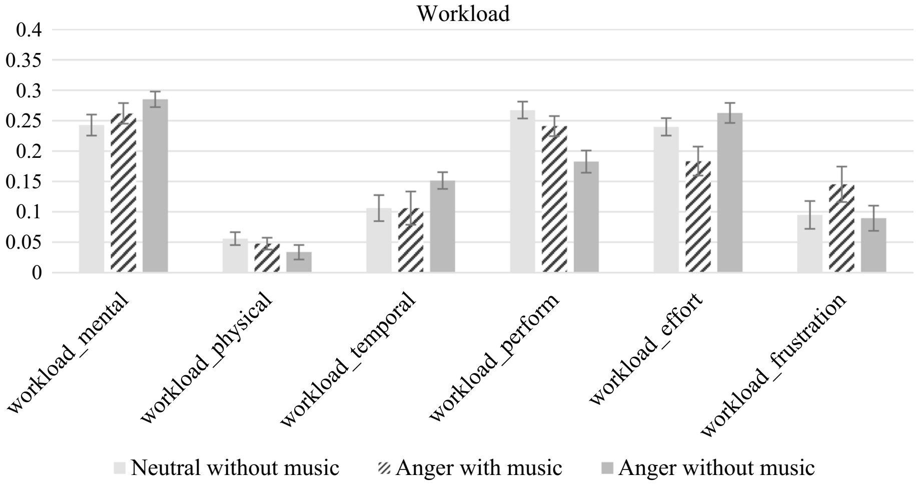
7.4 Questionnaires

7.4.1 Workload

Considering workload is important for designing any in-vehicle system. In this study, finding how much an in-vehicle music can add or reduce drivers' workload would be helpful. Several one-way ANOVAs were performed on workload factors to find if there are any differences among the groups. Results showed that workload-perform $F(2, 43) = 6.15$, $p < .05$ and workload-effort $F(2, 46) = 4.48$, $p < .05$ are significantly different among the groups (Fig. 10).

Workload-perform: Post Hoc tests with LSD shows that angry drivers who did not listen to any music ($M = .18$, $SD = .07$) rated their driving performance significantly worse than those angry drivers who drove with self-selected music

Fig. 10 Scores of groups for each workload subscale



($M = .24$, $SD = .06$, $p < .05$) and neutral drivers who drove without music ($M = .26$, $SD = .05$, $p < .05$).

Workload-effort: Post Hoc tests with LSD shows that that angry drivers who drove with music ($M = .18$, $SD = .09$) claimed significantly less workload-effort than angry drivers who did not listen to any music ($M = .26$, $SD = .06$, $p < .05$) and drivers in the neutral group ($M = .24$, $SD = .05$, $p < .05$).

7.4.2 DAS, DBQ, anger expression-out

Results of DAS and DBQ were not correlated with any of the driving errors. However, results from anger expression-out subscale were correlated with less fuel-efficiency driving behavior. It means that drivers with more anger expression-out style behavior had worse fuel-efficient driving performance ($r = .3$, $p < .05$).

8 Discussion

Making safe traffic environments mostly depends on drivers rather than vehicles, driving situations, and other environmental factors [1, 2]. Any changes in drivers' internal state can influence their driving behavior [51]. In this study anger as one of the common, impactful, and negative emotions in the driving context was investigated. Results of this experiment showed consistent patterns in drivers' performance, self-report data, and physiological reactions.

Results from drivers' self-report anger showed the successful anger induction procedure. Participants in the anger conditions reported significantly higher anger after the recall and writing procedure. This result reveals one aspect of emotion i.e., subjective feeling [35].

Based on Hypothesis 3, angry drivers' self-report of anger in music and no-music groups were compared to find whether the amount of anger decrements from emotion induction to the end of the experiment is different. This assumption was made to see if angry drivers in the music group reported more anger decrement than the drivers in the no music group. The results show no difference among angry drivers' self-report. Self-report emotion is a Likert-based scale questionnaire that may not be sensitive to small changes and not be able to reflect these patterns.

Consistent with the previous studies [33, 38, 51], in this experiment angry drivers showed deteriorated driving behavior than the neutral drivers. This finding supports the first hypothesis that angry drivers will show worse driving performance than non-angry drivers. Regarding the type of behavior, this difference is shown on fuel-efficient driving behavior. Angry drivers who did not listen to any music had worse fuel-efficient driving performance than the emotion-neutral drivers. Poor fuel-efficient driving behavior is defined as flooring the gas and brake pedals recognized by the driving simulator. Poor fuel-efficient driving was counted as risky driving behavior, as has been done in related studies [52, 53]. Roidl et al. [53] discussed the safety benefits of eco-drive training programs and their role on fuel efficiency and costs. In the nine principles of eco-driving, they discussed that “drivers should look and plan ahead and coast to traffic lights or intersections so that there is no unnecessary braking and the timing is such that the vehicle does not need to come to a complete stop.” For example, [54] found 35% fewer accidents with improvement in eco-driving behaviors. As shown in this and previous studies, fuel-efficient driving behavior is a valuable indicator of risky driving behavior.

Since emotional states can vary from moment to moment for different reasons, designing an in-vehicle system in cars to reduce the negative consequences of emotion via music would be helpful. Listening to music is a common and favorite activity in cars [20, 55]. Music creates emotions [56] or changes emotional states in its listeners. Although the results of driving behavior among the two angry driver groups did not show any significant difference (rejection of Hypothesis 2: angry drivers in the music group will show better driving performance than angry drivers in the no music group), the trend is consistent with this hypothesis. The trend shows worse fuel-efficient driving behavior in the angry drivers group who did not listen to music than those who listened to self-selected music. On the other side, there is no difference between music group and neutral drivers in terms of driving performance. This means angry drivers' performance in the music group is at the similar level as neutral drivers' performance. Similar results were found by [22] that self-selected music could improve driving performance. The music in the present experiment was drivers' self-selected music. They were asked to pick a music piece after the emotion induction procedure and were told that they would listen to that music while driving session. Therefore, there was no control over the musical features and the emotions of the music. Studies showed different effects of music mood on mitigating driver anger [33, 57].

The idea of an in-vehicle auditory system for angry drivers is not only based on self-report data. This system should be able to estimate drivers' emotional states indirectly via sensing and interpreting physiological data. To this aim, drivers' physiological data were recorded and analyzed. Hypothesis 4 predicted that angry drivers in the music group will show a different pattern in their physiological data than those in the no music group. To test this hypothesis, we compared the ECG and fNIRS data. Results showed that angry drivers who drove without listening to any music showed significantly higher HR than neutral drivers who did not listen to music and angry drivers who listened to self-selected music. This difference can be related to drivers' anger and arousal level. As shown in [58], anger is an emotion with negative valance and high arousal. High arousal is usually associated with higher HR [7, 12, 14]. Since we did not see the same pattern in the Anger with music group, we can conclude that self-selected music helped angry drivers and changed the arousal level back to that of the neutral state. In this experiment HRV did not show any difference among the groups. Moreover, as expected, we did not find a direct correlation between the self-report anger data and HR data. Since the results from the self-reported anger represent ordinal values, they are not sensitive to the intensity of the emotion as much as the physiological data.

Analyzing drivers' cardiovascular activity was not limited to between comparisons. To control over individual differences, drivers' cardiovascular activity was compared during the practice and the driving phases. Results showed that drivers' HR significantly increased from practice to driving sessions in the Anger without music groups and significantly decreased in the Neutral without music group. No significant changes were seen in the music group. These patterns imply that angry drivers who did not listen to music stayed angry, at least, during the driving session. However, angry drivers who listened to music during the driving had the same level heart rate as the practice session (before emotion induction), which shows the influence of music on drivers' HR data by regulating their arousal level. In other words, self-selected music kept drivers' arousal level the same as the neutral situation. The significant decrement in neutral drivers' HR data from practice to driving can be referred to the driving task itself. It has been shown that more than 70% of drivers listen to music more than two third of their driving time [55] and their main reasons are maintaining an optimal level of arousal and avoiding boredom.

Recording and testing drivers' hemodynamic changes of PFC were another aspect to assess drivers' emotional changes. Comparing the results of oxygenation and deoxygenation of PFC among the three groups did not show any significant differences. Moreover, there was no hemispheric difference. Although one benefit of fNIRS over fMRI is that fNIRS is not sensitive to motions as much [59], it may not be "zero". Individual differences and body movements may have added noise to the data. Therefore, like cardiovascular data, results of fNIRS were tested within the groups during the practice and driving sessions to control over individual differences. Results showed that in the Neutral without music and the Anger with music groups the average O2Hb significantly increased from practice to driving session. However, O2Hb level did not significantly change from practice to the driving session in the Anger without music group. Higher O2Hb level represents higher activity of PFC and higher activity in PFC is usually associated with emotional processing (both experiencing and regulating emotion) [39] and cognitive controls [60]. The difference in O2Hb level can be related to experiencing emotion, regulating emotion, and/or cogitative controls. Based on the results of driving behavior and cardiovascular activity, it seems that the higher activation of PFC in the Neutral without music and the Anger with music groups is related to cognitive controls and emotion regulation. Drivers in these two groups drove safer and did not show high arousal patterns associated with anger. Therefore, drivers in the Anger with music group could regulate their anger to some extent via music and have similar PFC activity to neutral drivers. However, drivers in the Anger without music group showed aggressive driving patterns which may be related to less concentration on the road and driving behavior in line with less PFC activity in the driving phase.

In the driving context the role of individual differences and some personality characteristics should not be ignored. Aggressive driving has been attributed to some personality characteristics. In this study, it was hypothesized that drivers who have anger-expression-out style and higher score in the driving anger scale will show worse driving performance (behavioral level) than other drivers (Hypothesis 5). Results supported half of the above notion. In other words, DAS was not correlated with any of the driving errors. This can be related to the driving scenario. In this study the hazards on the road are not similar to the hazards that were described in DAS items. However, anger expression-out was correlated with how much drivers showed fuel-efficient driving behavior. Drivers who had higher anger expression-out had worse performance in fuel-efficiency driving. This finding can support our interpretation that worse fuel-efficient driving behavior is related to anger and anger expression style.

To add a new system to cars for drivers, it is important to find how much it influences drivers' workload in any direction. Implementing an in-vehicle auditory display for angry drivers means adding something to the driving environment. The balance between being distracted from dangerous emotions like anger through music and not being distracted from the road via music is a thin boundary. Although in this study drivers' performance, music perception, and emotional changes were checked, measuring workload would give us more information especially when we need to generalize this simulation study results to a real driving context where it happens that drivers may drive for hours and miles. This study showed that angry drivers who did not listen to music rated their performance worse than the other groups. Moreover, they reported more effort to accomplish the driving task. Also, the use of music is even more promising given that angry drivers with music also felt less effort compared to neutral drivers without music. It seems that being distracted with anger adds to workload and music can reduce this workload by redirecting or regulating drivers' emotion to some extent.

9 Conclusion

Results of this study showed that music can help angry drivers. Based on the results of this study, to design an in-vehicle multimodal display for angry drivers, the below points should be considered:

1. The system should be able to monitor drivers' physiological reactions.
2. The system should be able to integrate subjective, behavioral, and physiological responses into a meaningful emotional state. For example, the system can interpret higher HR as high arousal and if it is accompanied by other variables (e.g., poor fuel-efficient driving behavior), the system can interpret it as anger.
3. The system should be sensitive to drivers' fuel-efficient driving behavior (e.g., speeding, abruptly flooring pedals). Results showed that other variables such as lane deviation, lane departure, etc. are not the main indicators of angry driving behavior.
4. The system should play mostly self-selected music.
5. The system should be customizable to drivers' personality characteristics e.g., anger response style.

In conclusion, this study found major contributing factors to driver anger. Overall, results showed the benefits of music for angry drivers. In this experiment self-selected music regulated angry drivers' arousal level. Moreover, they showed improved information processing through their behavioral data, fNIRS data and less workload.

10 Limitations and future work

Although this study has a holistic approach on assessing and controlling the variables related to emotion and driving behavior, a few points remained that should be considered in future studies. To control the influence of a specific kind of music on drivers' physiological reactions, one song was played on repeat during the driving session. It is possible that some of the drivers got irritated from the repetition of the song and this irritation influenced their emotional reactions. In the real world, drivers usually listen to a list of music or they turn off the music player for certain situations and future studies should control these factors.

Another point is the source of emotion. The emotion induction procedure in this study was based on recall of a personal memory. Drivers' anger is sometimes related to events on the road rather than a personal issue (integral vs. incidental emotions). It will be interesting to find out the differences of physiological patterns, reactions, and music perception between the two situations.

Moreover, the number of males and females in this study is not equal. This factor is important especially in emotion related topics where gender differences have been shown in previous studies and so, future studies should control this bias [61].

The low-fidelity simulator might have some limitations. With the small setup using a one monitor, our participants might not have fully immersed in the driving just as in real situations. If we use a higher fidelity, we might improve the sensitivity of the measures and provide the motion-based simulation, which will also influence drivers' physiological states. Nevertheless, previous research has demonstrated that a low-fidelity driving simulator or even a driving-like visuomotor game (e.g., [62]) can also obtain ecological validity (as its original meaning; see [63]) in the perceptual stimulus–response relationship.

Finally, in this study the intensity of the emotion was not controlled. As shown in the self-report results, most of the participants reported average anger after emotion induction (around 3 or 4 out of 7). Next studies should consider the influence of anger intensity on physiological patterns, music perception, and performance.

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