Am I Really Angry? The Influence of Anger Intensities on Young Drivers' Behaviors

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ABSTRACT

Anger can lead to aggressive driving and other negative behaviors. While previous studies treated anger as a single dimension, the present research proposed that anger has distinct intensities and aimed to understand the effects of different anger intensities on driver behaviors. After developing the anger induction materials, we conducted a driving simulator study with 30 participants and assigned them to low, medium, and high anger intensity groups. We found that drivers with low anger intensity were not able to recognize their emotions and exhibited speeding behaviors, while drivers with medium and high anger intensities might be aware of their anger along with its adverse effects and then adjusted their longitudinal control. However, angry drivers generally exhibited compromised lateral control indicated by steering and lane-keeping behaviors. Our findings shed light on the potentially different influences of anger intensities on young drivers' behaviors, especially the importance of anger recognition for intervention solutions.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI)**; • **Empirical studies in HCI**;

KEYWORDS

angry driving, intelligent agent, anger mitigation, driving performance

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1 INTRODUCTION

Driving is a complex and dynamic task that involves interaction with other road users (e.g., other vehicles and pedestrians) and objects (e.g., road infrastructure), which requires magnificent attentional resources and cognitive processing to maneuver, control, and plan [3]. However, the ability to carry out these activities can also be influenced by emotional states [3, 11]. A naturalistic driving study in the U.S. indicated that driving under an observable elevated emotional state—mostly anger—increased the crash risk by 9.8 times, which was even higher than other well-known driving distractions (e.g., texting using handheld devices increases crash risks by 6.1) [4].

Anger is a widely researched emotion that can lead to aggressive driving and negative impacts on driving performance in terms of lane-keeping errors and traffic rule violations [13]. Road rage and aggressive driving are more prevalent in young drivers [20]. Young drivers have immature executive functions [22] and are inexperienced in driving, which constrains their ability to plan and prioritize tasks under dynamic traffic conditions to drive safely. They are also easily overwhelmed and distracted by emotions [15], especially because young drivers tend to experience negative emotions more strongly [12]. Consequently, young drivers' misprioritized and divided attention can translate into motor vehicle crashes—the leading cause of teenage death in the U.S. [10]. However, despite the proneness of young drivers impaired by emotions, few attempts have been made to propose mitigation and training plans and evaluate them.

Our long-term goal is to develop affective solutions to train young drivers in mitigating anger effects on their driving performance. The first step is to understand and quantify how anger influences young drivers' behaviors. Although previous studies treated anger as a single state, not all levels of anger intensity may deteriorate driving performance equally. The Yerkes-Dodson Law suggested an inverted "U" relationship between performance and arousal level [23]. The research effort presented in the present paper is a work-in-progress project that attempted to induce anger with different intensities in the lab setting to understand if anger effects differ depending on anger intensities. This research project will make the first attempt to examine anger as a continuum on driving performance, filling the gap of missing affective components in cognitive driving models for decades [11].

In the present paper, we present the results from our first step in identifying the differences in the influences of anger intensity on driving performance. Our work has the following contributions. First, we identified a set of driving scenarios that potentially vary in their abilities to induce anger with different intensities. We also investigated the effectiveness of these scenarios in inducing anger using the Velten Mood Induction method [21]. Finally, we provided insights to guide the development of affective solutions to help young drivers mitigate anger effects on their driving behaviors. The following sections first introduced how we formulated materials to induce anger with different intensities. Then, we presented a driving simulator study along with its results on how anger intensities influenced young drivers' behaviors.

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Table 1: Clustering results for driving scenarios with different anger intensities.

Anger Intensity	# of Statements	Rating [*Mean* (*SD*)]	Rating Range	Example
Low	6	3.84 (0.02)	3.63 – 3.97	*I have been stuck on the road for many hours because of the heavy flood.*
Medium	12	4.32 (0.01)	4.16 – 4.50	*I see a person is using their phones while driving, which I think is a very unsafe practice.*
High	18	4.96 (0.03)	4.69 – 5.41	*I am trying to merge lanes, but another driver speeds up on purpose to not let me pass.*

2 METHOD

2.1 Anger Induction Materials Development

2.1.1 Collecting angry driving scenarios. To manipulate drivers' anger intensity in a controlled lab setting, we first collected anger-induced driving scenarios on the Amazon Mechanical Turk (MTurk) platform after getting approved from the University's Institutional Review Board (IRB). A total of 72 scenarios were collected from 24 participants (12 females, 11 males, 1 non-binary) aged between 24 to 48 (*Mean* = 30.21, *SD* = 7.50). After removing duplicated and highly similar scenarios, we then converted the scenario descriptions into self-statements (e.g., "I have been waiting for a long time in heavy traffic, and another vehicle suddenly merged into my lane."). A total of 40 statements were included in the next step of evaluating their anger intensity.

2.1.2 Categorizing scenarios into different anger intensities. A survey was developed and approved by the University's IRB before being distributed on MTurk to collect emotional ratings after reading those scenario descriptions. The task posted on the MTurk was restricted to nonrepeating US workers with a 95% and higher approval rating and 100 or more approved Human Intelligence Tasks (HITs), which means they have over 100 completed tasks approved as valid answers by the task requesters. We also applied several instrumental manipulation checks to ensure data quality [1, 9]. The survey profile—the targeting participants' gender and age distribution—was developed based on the demographic statistics from the Federal Highway Administration [6]. Participants were screened for gender and age to match the sampling profile. Eligible participants completed the survey that asked them to rate their emotional states (i.e., fearful, happy, angry, depressed, curious, embarrassed, urgent, bored, relieved, anxious) [12] on 7-point Likert scales after reading each self-statement related to the driving scenario. They also completed a survey asking about basic demographics and driving experience information.

Valid data from 36 participants (22 females) were included for further analysis. We performed a K-means clustering algorithm in R Studio to cluster driving scenarios into three levels of anger intensities based on the standardized anger ratings. The properties for each statement group are shown in Table 1. Considering that there were only six statements in the low anger intensity group, to create the induction material with equal number of statements within each intensity group, we also selected six statements from medium anger and from high anger intensity group each to maximize the differences among anger ratings across groups. These statements were selected for the Velten Mood Induction procedure [21] to manipulate anger intensity for the subsequent driving simulator studies.

2.2 Experimental Design

In a controlled lab environment, we conducted a driving simulator study to understand how different anger intensities influence driver behaviors. This study adopted a 3 (anger intensity: low, medium, high) x 2 (emotional state: neutral vs. angry) mixed-factors design, with the anger intensity as a between-subjects variable and the emotional state as a within-subjects variable. Participants first completed a drive under neutralized emotion and a second drive under induced anger of one of three intensities.

2.3 Participants

A total of 32 participants were recruited for this study and randomly assigned to one of three anger intensity groups. Two participants were excluded from the analysis due to not following the experimental instructions. The remaining 30 participants formed a gender-balanced sample for each anger intensity group. The demographic information and driving experiences for each group are presented in Table 1. The three groups did not differ in terms of their demographics or driving experiences (Table 2).

2.4 Apparatus and Stimuli

A simplified cab version of the National Advanced Driving Simulator (NADS)'s miniSim version 1.8.3.3 was used in this study. The simulation driving scenarios in this study were developed using the NADS Interactive Scenario Authoring Tool (ISAT) to include both highway (speed limit: 70 mph) and suburban (speed limit: 45 mph) areas. Four out of six driving-related anger statements resulted from the procedure described in Sections 2.1.1 and 2.1.2 were programmed into the driving scenario created for each anger-intensity group as driving-related angry triggers: the low-angry drive included rain, fog, snow, and unleashed dogs; the medium angry drive included a car violating the signal light and not yielding to pedestrians, a pothole with a naughty boy on the road, deer crossing the road, and a congested highway with another vehicle illegally passing; and the high angry drive included a slow-driving lead vehicle, a tailgating car honking at the subject driver, a congested segment with a following vehicle honking, and a vehicle cutting off the subject driver when merging onto the highway.

The driving scenario for the neutral drive was the same route as the one for the angry drive, but the starting and ending points were reversed. No anger-triggered events were included in the neutral

Table 2: Participant characteristics for each anger intensity group [*Mean* (*SD*)].

Anger Intensity	Age	Driving Experience (yr.)	Anger Trait	Anger State
Low	21.6 (2.39)	4.80 (2.39)	1.70 (0.31)	1.24 (0.18)
Medium	22.1 (3.51)	5.10 (2.47)	1.48 (0.17)	1.11 (0.21)
High	21.7 (2.54)	4.85 (2.24)	1.51 (0.13)	1.10 (0.11)

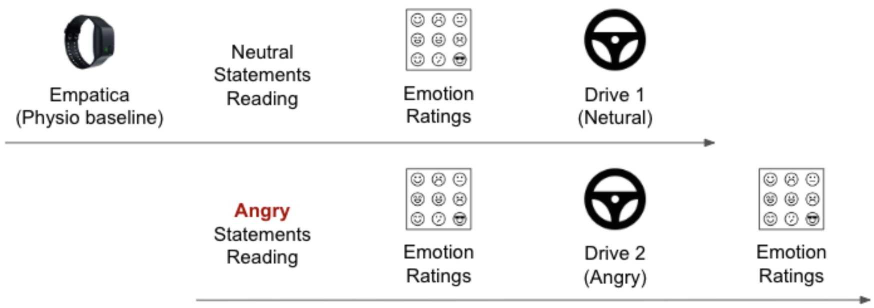

Figure 1: Experimental procedure after passing the simulator sickness check.

drive. Each drive lasted approximately 10 minutes. Driving performance data were automatically logged by the simulation system. We also used the Empatica E4 wristband to collect participants' heart rate throughout the entire study.

2.5 Procedure

Upon arrival at the lab space, participants were briefly introduced to the experimental procedure. After signing the consent form approved by the University's IRB, participants went through the simulator sickness test [8]. Eligible participants then filled out the demographic information and driving experiences, along with the State Anger and Trait Anger scales [16]. Figure 1 describes the subsequent experimental procedure. Then, participants were introduced to the Empatica E4 wristband, and their baselines were collected by asking them to stare at the plus sign on the computer screen for 5 minutes. After reading the neutral statements as instructed by the Velten Mood Induction method [21] and filling out their emotional state ratings, participants completed their first neutral drive. Then, they went through the Anger Induction procedure by following the instructions [5, 21] and reading out loud the anger-related driving scenarios selected in Section 2.1.2. Participants rated their emotions again after the induction, followed by the angry driving of their intensity group and the final emotion ratings. The entire study lasted approximately 45 minutes, and participants received $10 as compensation.

2.6 Dependent Measures and Data Preprocessing

In addition to the subjective emotional state ratings, we also collected objective measures that included physiological data and driving behaviors. Specifically, we are interested in heart rate variability (HRV) as an index of arousal and emotion regulation. In this study, we used the time domain feature–the square root of the mean squared difference of successive NN intervals (RMSSD)—to calculate HRV. During the study, we recorded time markers that segmented participants' data into five timings: baseline (5 minutes), neutral induction (3 minutes), neutral drive (~10 minutes), anger induction (~7 minutes), and angry drive (~10 minutes). We calculated the HRV for each time period using the "hrv-analysis" Python package (available at: https://github.com/Aura-healthcare/hrv-analysis).

As for the driving performance measures, we included longitudinal and lateral vehicle motor controls to evaluate driving performance. The average speed (mph), standard deviation of speed (mph), and average brake force (lbf) were used to assess longitudinal control. The maximum steering wheel angle rate (degree/s) and standard deviation of lane position (SDLP, ft) were used to evaluate lateral control.

3 RESULTS

3.1 Emotion Induction Manipulation Check

Figure 2 shows the overall mean rating scores of angry states at three timings: neutral, after anger induction, and after the angry drive. Results from the repeated measures analysis of variance (ANOVA) indicated that there was a statistically significant difference among the three timings: $F(2, 54) = 14.68$, $p < .001$, $\eta_p^2 = 0.35$. The pairwise comparisons with the Bonferroni adjustment indicated that the angry ratings after anger induction and angry drive were significantly higher than the neutral state (Figure 2). The angry ratings across different anger intensity groups did not differ significantly, $F(2, 27) = 1.34$, $p = .28$. There was no interaction effect between timings and anger intensity groups either, $F(4, 54) = 0.33$, $p = .86$.

3.2 Heart Rate Variability

Due to recording errors, four participants had missing segments and thus, were removed for further analysis. Finally, there were 10, 7, and 9 participants remained in the low, medium, and high anger intensity groups, respectively.

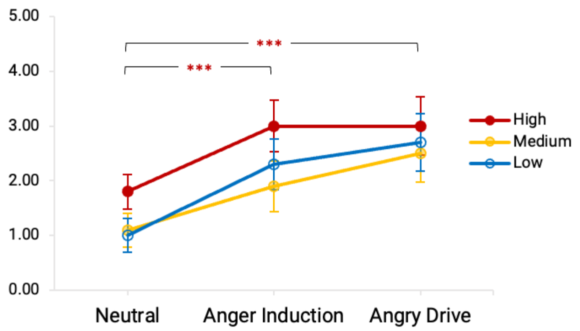

Figure 2: Anger rating scores across timings (* p <. 0003). [Error bars represent standard errors]**

Results from repeated measures ANOVA indicated that there was a significant main effect of the timing, $F(4, 54) = 5.62$, $p < .01$, $\eta_p^2 = 0.20$. The pairwise comparison using the Bonferroni adjustment indicated that participants' HRV was significantly larger during anger induction and angry driving compared to their baseline HRV or neutral induction HRV (Figure 3). However, there was no significant main effect of the anger intensity group, $F(2, 23) = 0.44$, $p = .65$, or an interaction between anger intensity and timings, $F(8, 92) = 1.21$, $p = .32$.

3.3 Driving Performance

We conducted a multivariate analysis of variance (MANOVA) to understand the effects of anger intensity and emotional state on driving performance measures as a whole. Results indicated a significant interaction effect between anger intensity and emotional state on the combined driving performance measures, $F(16, 40) = 2.46$, $p < .05$, Wilks' $\Lambda = .25$, $\eta_p^2 = 0.50$. The univariate tests indicated that there was a significant interaction effect for average speed [$F(2, 27) = 9.16$, $p < .001$, $\eta_p^2 = 0.40$] and standard deviation of speed (speed variance) [$F(2, 27) = 9.68$, $p < .001$, $\eta_p^2 = 0.42$], but not for other performance measures ($p > .05$). The simple main effects analysis indicated that within the low anger intensity group, participants had a higher average speed in the angry drive compared to the neutral drive ($p < .001$). Participants also had a larger speed variance in medium and high ($p < .001$) anger intensity groups compared to neutral drive (Figure 4).

We also found a significant main effect of emotional state on the combined driving performance, $F(8, 20) = 24.83$, $p < .001$, Wilks' $\Lambda = .09$, $\eta_p^2 = 0.91$. Further analysis indicated that participants had a larger average brake force [$F(2, 27) = 11.80$, $p < .01$, $\eta_p^2 = 0.30$], a higher maximum steering wheel rate [$F(1, 27) = 7.15$, $p < .05$, $\eta_p^2 = 0.21$], and a larger standard deviation of lane position (SDLP) standard deviation of lane position (SDLP) [$F(1, 27) = 6.05$, $p < .05$, $\eta_p^2 = 0.18$] in the angry drive compared to the neutral drive (Figure 5).

4 DISCUSSION

4.1 Differences in Ange-related Driving Scenarios

When clustering driving scenarios, we found that low anger-triggered scenarios—such as weather-related, unleashed dogs—tended to be non-social and not directly related to interacting with other road users. Drivers had less control over the low anger-triggered scenarios. The medium anger-triggered scenarios were more social and likely to be associated with other road users' unsafe behaviors but were not directly impact subject drivers, for instance, jaywalkers posing danger to themselves, another vehicle running a red light, other vehicles speeding, etc. Finally, high anger-triggered scenarios were social in nature and often affected subject drivers' traveling routes. Being cut off, being slowed down in a hurry, and being treated disrespectfully (e.g., other drivers honk aggressively, tailgate, or express rude gestures) are frequently mentioned scenarios with higher angry arousal. These findings can be useful in predicting driver reactions in response to road events, which could potentially benefit driver monitoring systems in providing proper intervention on time.

4.2 Angry Driving with Different Anger Intensities

Through a driving simulator study, we found some evidence indicating the influence of different anger intensities on drivers' HRV or driving performance. The primary reason for our minimal findings could be the power of the anger induction materials. Although the

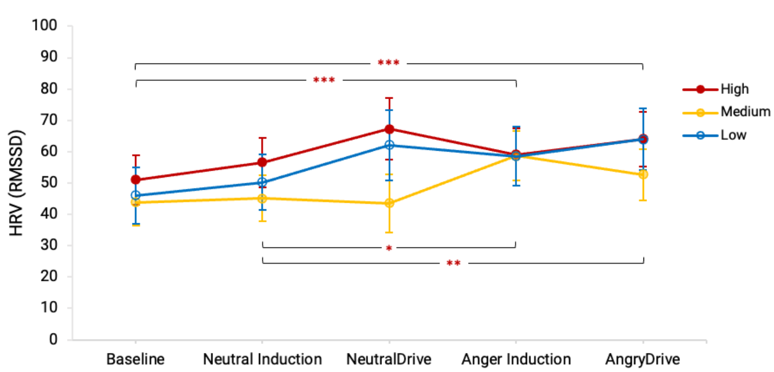

Figure 3: HRV across timings (Bonferroni correction: *$p < .005$, ** $p < .001$, *** $p < .0001$) [Error bars represent standard errors]

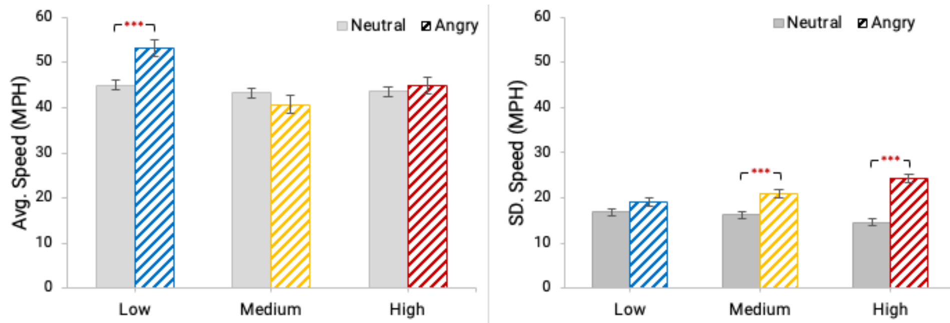

Figure 4: Interaction effect on Avg. Speed (left) and Speed Variance (right) (* $p < .001$) [Error bars represent standard errors]**

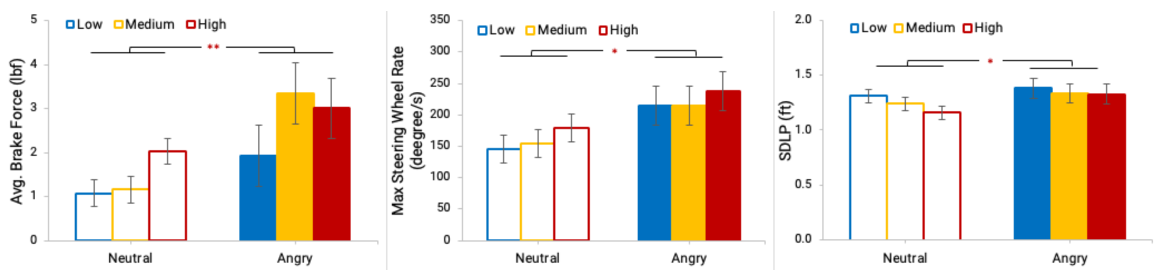

Figure 5: Main effects of emotional states on driving performance measures ($p < .01$, * $p < .05$) [Error bars represent standard errors]**

Velten Mood Induction method has been extensively validated and used in previous literature, the minimum number of statements used to induce emotion to date was 12 statements [14]. Despite that we have enough statements in medium and high anger intensity groups, the lack of statements in the low anger intensity group has limited the materials to six statements per group, which could compromise the effects of anger induction. Individual differences in responding to induction materials and their exposure time could also impact the anger induction effectiveness, which warrants further research.

Even with the limitations of the induction materials, we still found that participants' HRV was significantly larger when they were in the process of anger induction and during the angry drive, compared to their baseline resting period and their neutral induction period, which aligned with existing evidence that a higher HRV was one type of responses to anger induction and angry emotions [2, 7]. Thus, both subjective ratings and objective physiological measures supported the potential of the Velten Mood Induction method in inducing anger in driving simulator studies.

Although we were not able to induce different anger intensities as the subjective report indicated, our study still provided insights into understanding the nuanced effects of anger on driving behaviors. The interaction effect between anger intensity and emotion state indicated that although drivers with low anger intensity tended to drive at a higher speed compared to when they were not emotionally impaired, they were able to maintain the speed with little variance. However, drivers with medium and high anger intensities did not differ in their average driving speed compared to their neutral drive, but they demonstrated higher speed variance. A potential explanation of such observation is that drivers with low anger intensity might not recognize their emotions and thus, did not take compensatory behaviors to adjust their speed to travel safely. On the contrary, drivers with medium and high anger intensities might be aware of their emotional states and thus, actively adjusted their speed accordingly. We also identified the typical anger effects on driving behaviors in terms of braking and steering behaviors. Our findings aligned with the previous research that angry drivers were more likely to apply hard brakes [17] and were impaired in their lane maintenance skills [13]. Based on the findings, we can provide guidelines for drivers with different anger intensities. Across the angry drivers, the in-vehicle system can monitor their states and help them control brake pedals and speed in a more appropriate way. For drivers with low anger, the in-vehicle system can let them aware of their emotional state before it gets developed further because research shows that being aware of the individuals' emotional state per se can help mitigate emotional effects on their task [18].

4.3 Future Work

Although we confronted challenges in successfully inducing statistically different anger intensities, our results still indicate a potential to manipulate various anger effects based on its intensities. Specifically, we found that lower anger intensity was less recognizable by young drivers, which might prevent them from taking complementary actions to drive safely. To develop mitigation plans for anger impairment, future research could also look at helping drivers recognize their emotions before mitigating their effects. Further attempts could be made to refine the anger induction procedure by adding additional statements, which will have a longer induction period and might improve the probability of successful induction.

In the future, we plan to develop two affective training solutions using speech-based in-vehicle systems. Specifically, we are interested in using two prominent emotion-regulation strategies for the affective solutions: reappraisal and acceptance, which are associated with beneficial psychological health outcomes in the long term [19]. Cognitive reappraisal reframes an emotional stimulus to change its emotional impact, while acceptance requires accepting one's negative experiences without judgment [19]. We will make attempts to compose speech messages adopting each strategy in our subsequent study to assist drivers in anger regulation and in driving performance correction.

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