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Stress induction techniques in a driving simulator and reactions from newly licensed drivers

Yi-Ching Lee and Flaura K. Winston

Children's Hospital of Philadelphia

3535 Market Street, Suite 1150

Philadelphia, PA 19010, USA

Contact information for the correspondence author:

Yi-Ching Lee

Children's Hospital of Philadelphia

3535 Market Street, Suite 1150

Philadelphia, PA 19010, USA

Email: LEEY1@email.chop.edu

Phone: 1-267-426-5217

ABSTRACT

Challenging or unexpected traffic situations, which can induce frustration and other negative emotional states, can lead to unsafe, risky and aggressive driving behaviors. Although prior research has used a variety of techniques to induce emotions in drivers, their immediate reactions were not collected with driving metrics. Since teens, the age group with the highest crash risk, have limited emotion regulation skills and lack driving experience, they demonstrate maladaptive reactions to higher demand driving environments. Therefore, young drivers are important in studying the impact of emotions on driving. Since on-road studies pose too high a safety risk, driving simulation provides a safe environment in which to objectively expose young drivers to challenging traffic situations and to examine their immediate reactions and behaviors. This study aimed to develop and validate a new simulator protocol to induce negative emotional states in young drivers in order to examine the relationship between emotional states and driver reactions. In this study, dynamic stressful traffic events were selected for programming based on a systematic ranking of stress levels and a literature review, and young driver reactions were examined in the presence and absence of added time pressure. Self-reported data were collected from 33 young driver participants who reported their emotional states at four time points during the protocol. These data were then matched with vehicle control behaviors based on measures derived from the simulator. Results demonstrated the validity of the simulator protocol's stress induction manipulations. The simulated traffic situations resulted in emotional fluctuations over time, with a positive correlation between the magnitude of negative emotions and the number of unsafe behaviors. These newly licensed drivers did not cope well with the presence of slow-moving or braking cars in front. In conclusion, the traffic events in this new protocol were validated as stress-inducing by self-reported emotions and by demonstrated unsafe reactions and driving behaviors. Such a validated protocol can be used to develop and evaluate evidence-based interventions to help young novice drivers manage their emotions and to cope with stressful traffic situations and time pressures.

Key words: Emotion, Novice driver, Driving simulation, Validation, Stress induction, Time pressure

1. INTRODUCTION

Emotional states affect driving behaviors and outcomes (E. Roidl, Siebert, Oehl, & Hoger, 2013). Challenging or unexpected traffic situations, which can result in frustration and anger, have been shown to be associated with unsafe, risky and aggressive driving behaviors (Ge et al., 2014; Gulian, Matthews, Glendon, Davies, & Debney, 1989; Mursic, 2010) and at-fault crashes (Legree, Heffner, Psotka, Martin, & Medsker, 2003). Teen drivers, the age group with the highest crash risk (CDC, 2010), can be challenged by both limited emotion regulation skills (Dahl, 2008) and inexperience behind the wheel (Foss, Martell, Goodwin, & O'Brien, 2011). Therefore, young, inexperienced drivers demonstrate maladaptive reactions to higher demand driving environments, such as dynamic hazards, (Kaber, Zhang, Jin, Mosaly, & Garner, 2012) and are important in studying the impact of emotions on driving.

Most of the research in this area uses correlational analysis linking the relationship between self-reported emotional states with self-reported driver behaviors. For example, a survey study was conducted to examine the contribution of anger-related variables to explain traffic rule violations (Gonzalez-Iglesias, Antonio Gomez-Fraguela, & Angeles Luengo-Martin, 2012). Self-reported traffic violations were positively correlated with most of the Driving Anger Scale (DAS) (Deffenbacher, Oetting, & Lynch, 1994) subscales, including traffic obstruction and slow driving. Age was negatively correlated with hostile gestures and the Driving Anger Expression Inventory (Deffenbacher, Lynch, Oetting, & Swaim, 2002) subscales verbal aggressive expression, use of the vehicle to express anger and traffic violations. In another study, results from a population-based telephone survey showed that the prevalence of aggressive driving perpetration decreased with age, but the factors (e.g., stressful traffic situations) that contributed to aggressive driving remained generally stable across the lifespan (Wickens, Mann, Stoduto, Ialomiteanu, & Smart, 2011). While these studies demonstrated a link between emotion and negative driving behaviors and outcomes, such designs do not allow for the drivers' immediate reactions to emotionally charged traffic situations to be quantified and systematically examined. In response, several investigators have developed laboratory-based techniques to study the impact of emotions on driving.

1.1. Laboratory-based Induction Techniques

Inducing emotions in a lab-based environment is another way of studying their effect on driving behaviors. This approach has the potential to reveal the underlying mechanisms by which emotions affect driving behaviors. Three types of techniques have been used to induce general emotions and traffic-related emotions: 1) personal stories; 2) driving-relevant images or videos ; 3) programming challenging traffic situations in a simulator, a most recent technique.

The first technique involves recalling emotional events autobiographically and writing them down in detail, along with accompanying thoughts and feelings (Gilet, 2008). Researchers have used this technique to induce anger and to evaluate subsequent driving behaviors in a driving

simulator (Abdu, Shinar, & Meiran, 2012); results showed that, by comparison to drivers in the neutral emotional state, drivers in the angry emotional state crossed yellow traffic lights more frequently. In another study, participants recalled a very happy occasion, a very aggravating occasion, or a regular day in their lives (Taubman-Ben-Ari, 2012); results showed that the positive emotional stimulus led to a self-reported higher willingness to drive recklessly as compared with a neutral stimulus. Another study induced stress by asking participants to prepare a speech on their least favorite body part in five minutes and that the speech would be videotaped (Morton & White, 2013); results showed that as compared with music-listening relaxation induction, stress-induced drivers were worse at detecting restaurant signs and had more delayed braking upon seeing a pedestrian cross the road in a driving simulator. Overall, this technique shows that the induced emotions are carried over to subsequent driving activities. It is not possible, however, to quantify the magnitude of induced emotions and how subsequent behaviors are affected.

The second technique involves showing video recordings and images (Gilet, 2008) of driving situations and collecting drivers' reactions via self-report and in a simulator. One study used time pressure manipulations (either having to catch a train or calmly driving home) and measured drivers' impatience by showing car-driving relevant films, shot from the driver's viewpoint, that contained traffic situations where the car in front was stopping (Naveteur, Coeugnet, Charron, Dorn, & Anceaux, 2013). Results showed that, by comparison to the no time pressure group, the feeling of impatience started sooner and reached higher intensities for the time pressure group. Also, the time pressure group experienced a higher arousal level and more negative feelings. In another study, emotion-evoking images on an in-vehicle display were found to influence drivers' behavior in a driving simulator, with better steering performance associated with positive images and poorer steering performance associated with negative images (Trick, Brandigampola, & Enns, 2012). Another study used positive and negative words and presented them on virtual billboards in a driving simulator; results showed that drivers maintained a slower speed longer after seeing positive words (Chan & Singhal, 2013). Overall, this technique shows success in changing drivers' behaviors, but it is unclear how the drivers internalize and reason with the words or the videos; therefore, it remains a question as to the degree to which the stimuli led to changing behaviors. A recent study began to address this shortfall by comparing self-reports to physiological measurements during traffic hazards (Kinnear, Kelly, Stradling, & Thomson, 2013). Kinnear et al. collected participants' skin conductance responses and respiration while they watched the development of traffic hazards in videos. The analysis revealed that more experienced drivers showed stronger anticipatory physiological responses during the buildup of a hazard compared with inexperienced and learner drivers, although the self-reports of hazard ratings were not different between the three groups.

The third technique involves using dynamic traffic situations programmed in driving simulators to induce emotions. Anger was induced by traffic delays in the simulated environment (Fairclough & Spiridon, 2012), and results showed that traffic delays significantly increased

blood pressure and heart rate. A similar approach of having slower cars in front was used by Stephens and Groeger (2014); results showed that driving behind a slow car led to higher levels of reported anger and this reported anger was associated with closer following distance, faster speeds, and less compliance with the posted speed limit in the half-mile period after the anger-provoking events had occurred. Stress was induced by a periodic loss of vehicle control in a winter driving situation in a simulator (Funke, Matthews, Warm, & Emo, 2007), and results showed that the stress induction led to elevated post-drive distress, workload, mental demand, and frustration but did not lead to changes in lateral position, vehicle speed, and detection of pedestrians. These findings were based on the behaviors averaged across a drive and might have missed the chance to highlight the second to second fluctuations of vehicle control maneuvers while the stress-inducing event was occurring during a drive. In another study, frustration was induced by three unexpected traffic events (a parked car pulling out, a traffic light changing from green to red, and a dump truck slowly pulling out from a construction zone in front of a participant's car) in a driving simulator, as well as an opportunity to earn a bonus if completing the drive sooner (Oliver, Nigg, Cassavaugh, & Backs, 2012). By comparison to the baseline (no frustrating events or bonus) 60 seconds after encountering the frustrating events, participants deviated less from the lane center, showed better steering control and drove slower upon seeing a parked car pull out. However, participants deviated more, steered more, and drove faster when encountering the dump truck pulling out. This 60-second window was wide enough to potentially include the drivers' immediate reactions to the frustrating events, as well as any corrective and adaptive maneuvers deemed necessary to recover the 'wasted time.' Without directly examining the immediate reactions from the drivers, it was unclear how the frustrating events had impacted the drivers and their perceptions of the events.

Using dynamic traffic situations to induce emotion in a simulator has the advantage of immersing drivers in a realistic and interactive driving environment while observing drivers' reactions and behaviors in response to the traffic situations. What is missing in the literature is the analysis of drivers' immediate reactions while the traffic situations are occurring. In addition, some studies do not include other road users or dynamic traffic (e.g., cars, trucks, bicycles on the road) (Funke, et al., 2007; Morton & White, 2013). To date, studies report drivers' behaviors post-event or post-drive and do not capture drivers' interactions with the driving environment or other road users that are causing them to react. Given the prevalence of motor vehicle crashes in teens and young drivers and their maladaptive emotional regulations (Dahl, 2008; Kinnear, et al., 2013), it is important to establish the association between unsafe behaviors and negative emotions so that educational and interventional efforts can be designed to promote emotional cultivation in driving.

1.2. Objectives

This study built on the previous literature regarding emotion induction in driving and focused on measuring immediate reactions to emotionally charged traffic situations from a group of newly licensed young drivers. The primary objective was to validate the stress manipulations

programmed into a new simulator protocol by comparing objective and subjective measures of behavioral and emotional responses to the protocol among newly-licensed young drivers. Based on the results from previous correlational analyses, we hypothesized that drivers that were more affected emotionally by the traffic events had more unsafe behaviors as reactions to the traffic events.

Secondarily, since young drivers have not yet accumulated enough experience to foster adaptive behaviors in reaction to stressful traffic situations, they may not know the safest ways to handle their vehicle and to maintain a stable emotional state. The current study was designed to identify reactions and behaviors that prevented young inexperienced drivers from safely managing stressful traffic situations. Therefore, the second objective of the study was to identify patterns of reactions to the protocol that have safety consequences for newly-licensed young drivers. Based on the results of studies that implemented traffic delays, we hypothesized that traffic events in front that made drivers slow down would lead to more unsafe behaviors and a higher magnitude of negative emotions.

The third objective was to evaluate stress induction techniques in a driving simulator that allowed measuring interactive behaviors from drivers. Based on the significance of impact from time pressure manipulation in previous studies, we hypothesized that time pressure manipulation would lead to a higher magnitude of negative emotions.

2. METHOD

2.1. Participants

Thirty-three participants recruited from the community and nearby high schools and colleges participated in the study. All met the inclusion criteria of having had a driver's license for less than 6 months and being between 16 and 20 years of age. The average reported age was 17.76 yrs ($SD = 1.12$). There were 17 males and 16 females. Among them, 15 self-reported as having an African American or Black background, 10 as white, and 8 as other. None of them had participated in studies using a driving simulator. The ethnic breakdowns showed a representative distribution of local residents in West Philadelphia.

2.2. Materials and Apparatus

2.2.1. Driving Simulator

The simulator used was a high fidelity fixed-based simulator that consists of a Pontiac G6 driver seat, three-channel 46" LCD panels (160-degree field of view), with rearview, left side, and right side mirror images inlayed into the center, left, and right channels, respectively, active pedals and steering system, and a rich audio environment. The fully textured graphics are generated by SimVista, a tile-based scenario authoring software, and the real-time simulation and modeling are controlled by SimCreator, by Realtime Technologies, Inc.® Visual rendering and graphics

are delivered at 1280 x 1024 resolution with a 60-Hz frame rate. Three cameras were mounted to record foot movement, steering wheel maneuvers, and upper body movement. Simulations displayed on the center channel were also recorded. Data as well as video images were recorded by SimObserver and later reviewed via Data Distillery visualization software.

2.2.2. Simulated Drives and Descriptions

The study involved one practice drive (8 minutes) and two experimental drives (12 minutes each). The practice drive contained a 4-lane straight road, a short curved road section, and an intersection at which participants made a left turn onto a side street. The practice drive was assembled to allow participants to practice vehicle control and following directional signs. After a few minutes of driving on the straight road, the drive gradually became more challenging, with following a curve and making a left turn required.

The two experimental drives simulated a situation of going into the city and visiting a friend and then going to a function. Both drives consisted of a mixture of driving environments (i.e., 2-lane rural road, divided highway, and 4-lane urban road), different speed limits for each driving environment, representative buildings and landmarks, and traffic lights and stop signs. Directional signs would appear on the center channel a few seconds before an intersection at which participants needed to make a turn. Ten potentially stressful traffic events were included in the two experimental drives, and eight of them occurred in front of the driver and two behind the driver. The detailed process for choosing these traffic events were reported elsewhere (Y.-C. Lee & Bonfiglio, 2013) and are summarized here: 35 potentially stressful traffic situations were selected from the Driving Anger Scale (Deffenbacher, et al., 1994), as well as literature reviews. Each of the situations was then rated by 270 (ages 16 to 67) respondents on a 5-point scale, with 1 being not stressful and 5 being extremely stressful. The 15 situations that had the highest averaged ratings were then selected (see Table 1) and a process took place to evaluate the technical feasibility of implementing the situations in a driving simulator. In the end, ten of the situations were successfully implemented and subsequently used in the current study. Repeated internal testing within the research team was completed to ensure that the visual presentations of the ten situations were appropriate and realistic.

Table 1. Top 15 stressful situations and mean (SD) ratings

Situation	Mean (SD)
A police officer pulls you over	4.29 (1.00)
Someone backs right out in front of you without looking	3.65 (0.84)
Someone is driving right up on your back bumper	3.51 (1.13)
Someone cuts in and takes the parking spot you have been waiting for	3.34 (1.05)
You are preparing to merge into fast, heavy traffic	3.18 (1.17)
At night someone is driving right behind you with bright lights on	3.14 (1.07)
Someone honks at you about your driving	3.13 (1.14)
Someone is weaving in and out of traffic	3.09 (1.14)
You are driving in fog	3.08 (1.02)
Someone cuts in right in front of you on the freeway	3.08 (0.96)
You are driving behind a large truck and you cannot see around it	3.02 (1.09)
You are stuck in a traffic jam	2.95 (1.11)
You are driving closely behind a large truck	2.93 (1.19)
Someone runs a red light or stop sign	2.91 (1.16)
You are driving while it is snowing	2.90 (1.09)

2.2.3. Survey

The Driving Anger Scale (DAS, 14 items) (Deffenbacher, et al., 1994), the Impulsive Sensation Seeking Scale (ImpSS, 19 items) (McDaniel & Mahan, 2008; Zuckerman, Kuhlman, Joireman, Teta, & Kraft, 1993), and a customized emotional reporting scale, the Emotional Circumplex (EC) (Posner, Russell, & Peterson, 2005), were used to collect self-reported individual differences measures. For the DAS, participants were to imagine each traffic situation and rate the amount of anger the traffic situation would provoke in real-world driving on a 5-point scale (1 = none at all; 5 = very much). For the ImpSS, the items involve a lack of planning and the tendency to act impulsively without thinking, and participants were to read and respond to each statement by deciding if the statement was true or false to them. If they did not like either choice, they were to mark the choice they disliked the least.

For the EC, they were to report their current feelings on two dimensions: worked-up vs. numb (arousal) and positive vs. negative (valence). Worked-up is defined as being alert and quick to react. Numb is defined as being unresponsive and slow to react. Positive is defined as feeling good. Negative is defined as feeling bad. Participants were to place a dot on a two-dimensional grid, with negative vs. positive on the horizontal axis and worked-up vs. numb on the vertical axis (see Figure 1). They could mark in any of the four quadrants or anywhere on the vertical or horizontal lines defining the quadrants. For example, as in Figure 1, if the participant felt both positive and worked-up, he would assess the magnitude of the two dimensions and place a dot in the upper-right quadrant. Similarly, if he felt both positive and numb, he would then place a dot in the lower-right quadrant. If he felt neither positive nor negative and felt a little worked-up, he would place a dot in the 0 position along the valence dimension that intersected with the felt magnitude on the arousal dimension. Later, the location of the mark was transformed to a

numeric format: having a positive rating of 7, a worked-up rating of 2, a negative rating of 0, and a numb rating of 0 as in Figure 1.

We also collected self-reports on demographic information (including student status, ethnic background), perceived simulation realism, and participant's description of themselves as a driver.

Figure 1. Emotional circumplex as a two-dimensional grid with zero in the middle.

2.3. Procedure

Participants first completed the consent process and verification of eligibility. The entire study procedures took approximately one and a half hours to complete. Table 2 lists the stimuli presented and variables collected at each of the time points.

During time point #1, each participant was asked to fill out three surveys – Driving Anger Scale, Impulsive Sensation Seeking Scale, and Emotional Circumplex. The instructions for each survey were presented in writing and verified verbally by an experimenter.

Upon completion of the surveys, participants were invited to sit in the simulator and adjust the seat and back support. The experimenter then oriented the participants by pointing out the locations of the mirrors, turn signal activations, dashboard, and center console. The experimenter also pointed out an emergency stop if participants needed to end the simulation during the study session. Then, the experimenter provided the following instructions to the participants: follow the speed limits and the directional signs presented in the center display, remain in the right lane

until told to change lanes, and drive safely and legally. Participants took a practice drive to become familiar with the visual presentations of the simulation and vehicle dynamics. During the practice drive, the experimenter stood next to the participant and pointed out traffic lights, speed limit signs, and directional signs to ensure that the driver saw them and understood what they depicted.

The instructions for the first experimental drive emphasized the need for participants to drive safely, handle traffic situations, and obey traffic laws. Once they understood the instructions, participants began the first experimental drive by pulling out of a parking lot and turning right to join the road. The experimenter monitored the study session and noted any observable violations of the traffic laws (i.e., instances that would result in getting tickets in the real-world). If participants missed the directional signs and did not know how to proceed through intersections, the experimenter would give them directions or direct them back to the scripted route. This drive ended when participants pulled into a driveway on the left of the road and stopped the car. At time point #2, participants' current emotions and the vehicle control variables from the simulator were collected. Then, participants were free to take a short break.

Table 2. Stimuli presented and variables measured at each time point.

Time	Stimuli	Variables collected	Calculations	Analytical Methods
1 (pre-drive)	Driving Anger Scale	Rated anger at hypothetical traffic situations	Summation of ratings	Correlation with unsafe behaviors
	Impulsive Sensation Seeking Scale	Sensation seeking and impulsivity	Number of 'true' items (reverse coding for reversed items)	Correlation with unsafe behaviors
	Emotional Circumplex	Marked emotion on 2-dimensional grid	Transformed to numeric format	Changes over 4 time points
2 (end of 1 st experimental drive)	5 traffic events during drive	Vehicle control variables	Unsafe behaviors (e.g., speeding) for each traffic event and number of tickets from this drive	Correlation with survey results
	Emotional Circumplex	Marked emotion on 2-dimensional grid	Transformed to numeric format	--
3 (end of 2 nd experimental drive)	5 traffic events during drive	Vehicle control variables	Unsafe behaviors (e.g., speeding) for each traffic event and number of tickets from this drive	Correlation with survey results
	Emotional Circumplex	Marked emotion on 2-dimensional grid	Transformed to numeric format	--
	Retrospective	Marked	Transformed to numeric	Relative

	emotional reporting for 8 traffic events	emotion on 2-dimensional grid	format for each of 8 events	comparisons among 8 traffic events
4 (exit of study)	Demographic questionnaire	Driving experience	Subjective ratings; descriptive statistics	Qualitative analysis
	Emotional Circumplex	Marked emotion on 2-dimensional grid	Transformed to numeric format	--

The instructions for the second experimental drive emphasized that a driving bonus would be available by reaching the destination and that any illegal or dangerous driving would result in losing part or all of the bonus, just like getting a ticket in real-world driving (e.g., speeding would lead to the deduction of \$5 and crashing the vehicle would result in no bonus). In addition, for participants randomized into the time pressure group, they were told their bonus started at \$75 but would drop \$5 every minute they were driving. Thus, they would want to get to the destination as quickly as possible. This bonus calculation is similar to that of Fairclough and Spiridon (2012). Once the participants understood the instructions, they began the second experimental drive by accelerating to a desired speed in a two-lane road. The experimenter monitored for and noted any violations. This drive ended when participants came to a parking lot and stopped the car. At time point #3, participants' current emotions and the vehicle control variables from the simulator were collected. Then, the experimenter seated the participants in front of a computer to watch the video recordings of the two experimental drives. Participants reviewed each of the eight events that occurred in the forward view and reported their emotions retrospectively (using the 2-dimensional grid) as the event was occurring. They also were encouraged to briefly describe what the event meant to them and how they handled it. This video reviewing and reporting procedure is similar to that of Naveteur, et al. (2013).

Finally, at time point #4, participants answered a few demographic questions and a few questions about the realism of the drives. They were also asked to describe themselves as a driver and to report their current emotions one last time. During this time, the experimenter calculated the amount of bonus and then compensated and debriefed the participants.

2.4. Data Processing and Dependent Variables

Table 2 summarizes the calculations performed on each collected variable and the analytical method performed for testing the hypotheses. The details for processing the collected variables are presented below.

2.4.1. Simulator Data

We first went through each programmed event and examined for specific unsafe behaviors, including whether or not participants showed signs of recognizing a potentially hazardous situation and how they acted or reacted, including any observable stress reactions (e.g., honking).

When relevant, we also examined their speed or acceleration/deceleration profile to better determine if they recognized the hazard. This process was similar to that of Lee et al. (2008) for identifying performance evaluation metrics. For example, for the event that a motorcyclist ran a red light on a cross street in front of participants, indications we looked for were a) whether participants did a traffic check (looked right-left-right) as they approached the intersection, b) did they brake or slow down as they approached the intersection, c) the recorded speed before braking or crossing path with the motorcyclist, d) the timing of noticing the motorcyclist (before or after they entered the intersection). Once the evaluation metrics were identified, the next step was to determine participants' unsafe driving scores for each programmed event. Because of the nature and the intensity of the events, each event was scored differently in order to capture the most unsafe behaviors as poor reactions to the event. The start and end of each event was defined and then continuous and categorical variables were identified. For continuous variables (e.g., speed), we used the mean to divide the participants into categories (e.g., transforming a numbered speed to a high or low speed). Then we assigned 1 unsafe driving score to 'high speed' (e.g., participants having a speed that was above the mean speed right before braking as a response to a vehicle suddenly pulling out received 1 unsafe driving score). For categorical variables (e.g., early or late recognition of a motorcycle running a red light), we assigned 1 unsafe driving score to the unsafe or less safe behavior. The maximum unsafe score varied among the event, and it could range from 1 to 4, depending on the length and intensity of the event. Third, we examined for illegal or dangerous maneuvers during each of the experimental drives (e.g., collision, driving on the wrong side of road) and determined the number of 'tickets' participants would have received if the drive were to take place in the real world. Lastly, three raters went through the videos, the collected numerical data, and the calculated derived variables and determined the unsafe scores and the number of tickets. Team meetings were held to discuss the results and to resolve the discrepancies. In the end, each participant logged an unsafe score for each event, the accumulated unsafe score for each experimental drive, and number of tickets for each experimental drive.

2.4.2. Surveys

Standard calculations were used to score the Driving Anger Scale (summation of cumulative ratings) and the Impulsive Sensation Seeking Scale (summation of occurrence of 'true' statements). The total scale scores were used for the analysis. For other force-choice survey questions, summary statistics were applied. For open-ended survey questions (for example, describe yourself as a driver), one rater processed and coded the responses according to a previously developed codebook.

2.4.3. Emotion Reporting

EC was used at each of four time points, and the ratings were transformed into a numeric format (i.e., Positive, Negative, Worked-Up, and Numb) based on the location of participants' marks. For example, a rating within the upper right quadrat would be denoted as having a positive rating

on Positive and Worked-up and having a zero on Negative and Numb. This process was repeated for each participant and for each time point (i.e., pre-drive, end of first experimental drive, end of second experimental drive, and exit of study) as well as for the eight events during retrospective ratings.

2.4.4. Analyses

As a manipulation check, we assessed the changes on reported emotional states over time. This was to demonstrate that the simulated traffic events produced emotional fluctuations. The distribution of changes over the four time points, as well as pair-wise comparisons between two time points, were performed.

Additionally, analyses were performed to test the study hypotheses:

Hypothesis 1: Drivers that were more affected emotionally by the traffic events had more unsafe behaviors as reactions to the traffic events. Correlations were used to assess the association between subjective emotional reports and objective vehicle control variables.

Hypothesis 2: Traffic events that made drivers slow down or brake led to more unsafe behaviors and a higher magnitude of negative emotions. Descriptive statistics were used to compare the unsafe scores and retrospective emotional reports across traffic events.

Hypothesis 3: Participants in the time pressure condition reacted more strongly by having a higher magnitude of negative emotions. T-tests were used to compare the self-report emotions between the time pressure conditions.

3. RESULTS

3.1. Manipulation Checks - Report of Emotion

First, we checked if there were differences on emotional ratings over the 4 time points (pre-drive, end of 1st experimental drive, end of 2nd experimental drive, and exit of study). There were significant differences for the positive, $F(3,94) = 6.17, p = .0007$, worked-up, $F(3,94) = 2.92, p = .0381$, and negative, $F(3,94) = 10.35, p < .0001$, ratings for all participants.

Next, paired t-tests were used to examine the mean differences between two time points for the positive, worked-up and negative ratings. Figure 2 shows the means of the ratings. The positive ratings decreased significantly from Time 1 to Time 2, $t(31) = 3.56, p = .0012$, remained similar from Time 2 to Time 3, and increased significantly from Time 3 to Time 4, $t(31) = 2.71, p = .0109$. This pattern was reversed for the negative ratings, increasing significantly from Time 1 to Time 2, $t(31) = 3.83, p = .0006$, remaining similar from Time 2 to Time 3, and decreasing significantly from Time 3 to Time 4, $t(31) = 3.17, p = .0034$. For the worked-up ratings, the only significant difference was detected between Time 3 and Time 4, $t(31) = 2.96, p = .0059$, and the

increase of ratings from Time 1 to Time 3 was gradual. Overall, the stress manipulations led to emotional fluctuations across time points.

Figure 2. Means of emotion ratings at four time points.

3.2. Correlations between Subjective and Objective Measures

We tested the first hypothesis that drivers who were more affected emotionally by the traffic events would have more unsafe behaviors as reactions to the traffic events. Indeed, there were positive correlations between the negative ratings and unsafe scores at Time 2, suggesting that drivers who had more negative or worked-up emotions showed more unsafe reactions (either as the number of tickets or the unsafe scores) to the stressful events (see Table 3). Interestingly, we did not observe the same patterns at Time 3 or among the participants in the time pressure condition.

Table 3. Correlations between subjective and objective measures at Time 2

Pearson r <i>p</i> value	Positive rating	Worked up rating	Negative rating	Ticket	Unsafe score	Ticket + unsafe score
Positive rating	--					
Worked up rating	-.04 .8187	--				
Negative rating	-.61 .0002*	.27 .1295	--			
Ticket	-.47 .0110*	.49 .0071*	.34 .0723	--		
Unsafe	-.31	.32	.46	.46	--	

score	.1040	.0952	.0114*	.0125*		
Ticket + unsafe score	-.39 .0340*	.41 .0278*	.48 .0077*	.68 <.0001*	.96 <.0001*	--

* denotes reaching .05 significance level.

Exploratory analyses showed that the DAS score was positively correlated with ratings of worked-up, $r(33) = .45, p = .0088$, and ImpSS score, $r(33) = .57, p = .0005$. These correlations were in the expected directions, suggesting that the measures we used were appropriate for picking up individual differences in the context of emotions and driving outcomes.

3.3. Comparison among Traffic Events

We then tested the second hypothesis that traffic events that made drivers slow down or brake would lead to more unsafe behaviors and higher magnitude of negative emotions via retrospective reporting. Because the length and intensity of the events was different, descriptive statistics were used for comparing the unsafe scores and retrospective ratings across the events. The accumulated unsafe scores and number of tickets were not different between drives 1 and 2. The averaged unsafe scores and number of tickets across the two experimental drives were 3.84 and .95, respectively.

Table 4 lists the event descriptions, unsafe scores, and the associated retrospective ratings of emotion from the retrospective review of eight events that occurred in front of the drivers. The averaged emotional ratings across the two experimental drives were .59 for positive ratings, 2.90 for worked-up ratings, 3.01 for negative ratings, and .85 for numb ratings. Overall, traffic events that generated higher ratings on negative and worked-up were related to having obstacles in front that made the drivers brake or drive slower, such as ‘Someone runs a red light in front’ and ‘There is stop-and-go slow traffic in front.’

Table 4. Unsafe scores and retrospective emotions by traffic event

Event description	Behaviors collected at	Calculated, averaged unsafe score	Retrospective emotional rating			
			Positive	Worked-up	Negative	Numb
Someone pulls out of traffic in front	Time 2	0.66	0.24	2.55	3.06	0.64
Someone runs a red light in front	Time 2	1.69	0.15	4.64	3.73	0.33
Someone weaving in and out of traffic in front	Time 2	0.63	0.72	2.56	2.75	1.13
I need to change lanes in fast heavy traffic	Time 2	0.54	1.39	0.84	0.90	1.68
There is stop-and-go slow traffic in front	Time 3	1.46	0.22	4.03	4.56	0.63

I need to merge into fast heavy traffic	Time 3	0.54	1.38	2.28	1.91	0.84
I am driving behind a large truck without visibility to see around it	Time 3	0.93	0.16	3.88	4.44	0.84

Note: One event “Someone cuts in front on the highway without enough gap” did not materialize consistently. Its ratings were not presented in the table.

3.4. Time Pressure Conditions

We tested the third hypothesis that participants would react more strongly in the time pressure condition. Time pressure manipulations led to a larger change in emotion from Time 3 to Time 4 when compared with the baseline (no time pressure) condition, as reflected in the worked-up (Figure 3) and negative ratings (Figure 4), $t(16) = 2.22, p = .0409$, $t(16) = 2.99, p = .0087$, respectively.

Figure 3. Worked-up ratings at four time points for the two time pressure conditions.

Figure 4. Negative ratings at four time points for the two time pressure conditions.

3.5. Simulation Realism and Driving Experience

Descriptive statistics were used for analyzing the demographic questionnaire. Because our manipulations included time pressure and consequences for not driving legally, we needed to make sure that the simulations and the instructions were realistic and appropriate so that the observed behaviors can be scaled up to real-world driving. When participants were asked about the realism of the simulations, 29 out of 33 thought the simulation looked real and 19 out of 33 reported that they drove in the simulator the same way as in real life. Additionally, the sample of the participants showed a variety of responses when asked to describe themselves as a driver, ranging from very conservative (e.g., "Since I am new to driving, I always drive slowly and only drive when the weather is nice") to very aggressive (e.g., "I like to speed and race with other drivers on the road").

4. DISCUSSION

The first objective of the study was to compare objective and subjective measures from newly-licensed drivers across time and stress manipulations, and we hypothesized that drivers who were more affected emotionally by the traffic events had more unsafe behaviors as reactions to the traffic events. The results showed that the stress induction manipulations (traffic events and time pressure) led to corresponding changes in emotional states across time. The presence of stressful traffic events significantly increased negative feelings. Upon completion of the simulator drives, participants' negative feelings went back to neutral. Drivers who had more negative emotions showed more unsafe reactions to the stressful events. These findings suggest that the stressful scenarios were validated, at least partly, by the self-report emotions for the induction of negative feelings, confirming the approach of using self-reports for validating the use of driving simulators as a tool for measuring behaviors (de Winter, 2013; Reimer, D'Ambrosio, Coughun,

Kafrissen, & Biederman, 2006). Our results confirmed previous findings (Stephens & Groeger, 2014) and suggest that stressful events, drivers' perceptions of such events, and drivers' emotional reactions are highly related to each other, and newly licensed teen and young drivers are affected by the stress-inducing traffic events even though they have only had a limited amount of experience in driving.

The second objective of the study was to identify patterns of behaviors that have safety consequences for newly-licensed drivers and we hypothesized that traffic events in front that made drivers slow down would lead to more unsafe behaviors and a higher magnitude of negative emotions. Some events led to a relatively higher number of unsafe behaviors and these seemed to include a slower car or unexpected perpetrator in front, causing the driver to brake or react within a short time. These events also seemed to generate a higher rating of negative and worked-up emotions. One common element in these events seems to be someone blocking the driver's way, confirming other findings in the literature (Ernst Roidl, Frehse, & Hoyer, 2014), and this pattern has safety implications: a) Drivers may not have anticipated or recognized the actions of nearby cars. This speaks to the need to be better aware of dynamic traffic situations. Some researchers have looked into training and intervention opportunities to allow new or young inexperienced drivers to learn how to detect and respond to potential hazards (Garay-Vega, Fisher, & Pollatsek, 2007; Pradhan, Pollatsek, Knodler, & Fisher, 2009). Results showed that this skill is trainable, and the learned knowledge can be transferred and applied to new, unseen driving environments; b) Drivers may have associated the actions of other cars with bad intentions, as evidenced by the elevated negative emotions. Lennon and Watson (2011) found that retaliation was common when drivers perceived deliberate intent from other drivers and responded aggressively in return; c) Drivers may have felt the need to drive more quickly and, when this was not possible due to slowed or stopped cars ahead, they expressed a higher level of negative emotions and behaviors. Research has shown that time pressure has become a cultural phenomenon that goes beyond a personality factor (S. Coeugnet, Charron, Van De Weerd, Anceaux, & Naveteur, 2011; Stephanie Coeugnet, Miller, Anceaux, & Naveteur, 2013). Taken together, interventions and educational efforts are needed for teaching teen and young drivers to cultivate a balanced emotional state and to be better aware of changes in the driving environments.

Third, we implemented a time pressure manipulation and hypothesized that this manipulation would lead to a higher magnitude of negative emotions when compared with a no-time pressure manipulation. Time pressure led to a change on participants' worked-up and negative ratings toward the end of the study procedures but we did not see a significant change between the two experimental drives. Because this manipulation was tied to a monetary bonus, we suspected that this time pressure contextual factor might have meant differently for the participants. For some, who cared about their final bonus amount, this manipulation gave them a reason to try to reach the destination sooner; for others, who did not care as much about the final bonus amount, this additional manipulation did not change their typical driving behaviors. This finding seems to

suggest that the associations among traffic contextual factors, emotions, and behavioral reactions are not simple and they depend on drivers' interpretations and perceptions (Kinnear, Helman, Wallbank, & Grayson, 2015). Future studies should examine how drivers interpret traffic contextual factors, especially in ambiguous situations, and how the interpretations influence their subsequent behavioral reactions and emotions.

Based on participants' self-reported assessment of simulation realism, dynamic traffic interactions, as well as representative roadway scenes, led to an immersive virtual driving environment, and most participants felt they drove the same way in the simulator as in real-world driving in a car. We also programmed the traffic events in such a way that we could collect and measure a wide range of reactions (e.g., we programmed a police car to pass the participant vehicle if the participant decelerated the vehicle to be below 20 mph but remained behind the participant vehicle if the participant maintained a speed above 21 mph). With our simulator set-up we were able to review participants' foot movement, turn signal activation behaviors, and honking from recordings of video cameras. These and the numerical data related to vehicle control collected by the simulator increased the fidelity of the simulations in quantifying subtle behaviors and reactions that led to participants' coping with stressful traffic events.

However, our study had a number of limitations. One stressful event did not materialize consistently across the participants. This event was designed to take place about two-thirds into a highway environment. Some drivers who maintained a speed close to the speed limit saw the event at the intended time; however, other drivers who either drove too slowly or were too far away did not experience this event as planned. Therefore, we did not calculate the unsafe scores for this event. Updates are needed for better control of the onset and the timing of the event. In addition, we did not recruit a group of drivers that are more experienced and skilled as a comparison. We would expect to see safer reactions and more balanced emotions from experienced drivers, thus providing further validation that emotions play an important role in driving, especially when traffic situations are stressful.

5. CONCLUSIONS

This study was designed to examine the emotion induction techniques in a driving simulator and to measure the reactions and behaviors upon experiencing stressful traffic situations and time pressure manipulations from a group of newly licensed young drivers. Our results showed that the proposed stress induction manipulations were effective in causing participant drivers to react emotionally and behaviorally. Yet, the simulations were perceived as representative and realistic. Our measurements were appropriate for identifying individual differences in the context of safe driving behaviors around stressful traffic situations among a group of newly licensed drivers. Even though the time pressure manipulation only showed a modest effect, all the other findings supported the design and validation of a simulator-based stress induction paradigm that can now be used to further study the behaviors of newly licensed drivers.

A few patterns of unsafe behaviors emerged from examining drivers' emotions and reactions as the stressful events were occurring. Newly licensed drivers in our sample did not cope well with the presence of slow-moving or braking cars in front. These patterns speak to the need for developing evidence-based interventions to help young novice drivers manage their emotions and to cope with stressful traffic situations and time pressures.

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