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Anger Effects on Driver Situation Awareness and Driving Performance

Abstract

Research has suggested that emotional states have critical effects on various cognitive processes, which are important components of situation awareness (Endsley, 1995b). Evidence from driving studies has also emphasized the importance of driver situation awareness for performance and safety. However, to date, little research has investigated the relationship between emotional effects and driver situation awareness. In our experiment, 30 undergraduates drove in a simulator after induction of either anger or neutral affect. Results showed that an induced angry state can degrade driver situation awareness as well as driving performance as compared to a neutral state. However, the angry state did not have an impact on participants' subjective judgment or perceived workload, which might imply that the effects of anger occurred below their level of conscious awareness. One of the reasons participants showed a lack of compensation for their deficits in performance might be that they were not aware of severe impacts of emotional effects on driving performance.

1 Introduction

The evidence supporting subliminal or implicit perception comes from various experimental sources. One of the salient examples is emotional effects. For example, research has shown that subliminally flashed pictures displaying emotionally positive or negative scenes impact the judgments of neutral pictures of people (Murphy, Zajonc, & Monahan, 1995). These subliminally presented emotional stimuli even activate cortical areas that mediate emotional experience (Whalen et al., 1998). However, relatively little research has been conducted regarding emotional effects on a dynamic situation such as driving or aviation. Of the research on emotion within these dynamic situations, a focus has been placed on the effects of emotions on performance outcomes, but not on possible underlying mechanisms. For example, research has shown that anger negatively influences various driving performance and risky behaviors such as infractions, lane deviations, speed, and collisions (Deffenbacher, Deffenbacher, Lynch, & Richards, 2003; Jeon, Yim, & Walker, 2011; Underwood, Chapman, Wright, & Crundall, 1999). However, questions about the underlying mechanisms of the effects still remain unanswered.

People are generally blind to their emotional feelings, even when they think they are well aware of them (Picard, 2010). Even when individuals are aware of

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(or expect) their emotional state, it can still tremendously influence people's cognitive processes and behaviors if they are not aware of the potential *effects* of that emotional state. The current paper attempts to identify the *underlying mechanism* of these powerful emotional effects, specifically anger, on driving performance in relation to situation awareness. To the best of our knowledge, there is no research on the relationship between emotional effects and situation awareness.

2 Emotional Effects on Cognition

Emotions have enormous effects on cognition, ranging from selective influences on each stage of information processing to overall influences on information processing style, such as the relative weight given to top-down and bottom-up processing (Lee, 2006). To illustrate, emotions influence the perception and organization of memory (Bower, 1981); categorization and preference (Zajonc, 1984); goal generation, evaluation, and decision-making (Damasio, 1994); strategic planning (LeDoux, 1992); focus and attention (Derryberry & Tucker, 1992); motivation and performance (Colquitt, LePine, & Noe, 2000); intention (Frijda, 1986); communication (Birdwhistle, 1970; Chovil, 1997; Ekman & Friesen, 1975); and learning (Goleman, 1995). For a recent review of influences of emotions on higher level cognition such as interpretation, judgment, decision-making, and reasoning, see Blanchette and Richards (2010).

Traditionally, psychological sciences have suggested various theories on the relationship among emotion, physiological arousal, and cognition (e.g., the James–Lange theory [James, 1884], the Cannon-Bard theory [Cannon, 1927], and the Two-Factor theory [Schacter & Singer, 1962]). One of the unresolved issues is whether affective processes should be considered as a part of the cognitive representational system or as an entirely separate mental faculty (Fiedler, 1988; Hilgard, 1980; Salovey & Mayer, 1990). Zajonc (1984) showed that emotions can be aroused without the participation of cognitive processes and thus, can function independently. Other theorists also underlined the possibility that affect is external to, and may independently inform, cognitive outcomes (Clore, Schwarz, & Conway, 1994; Niedenthal, 1990; Schwarz & Clore, 1988; Strack, Martin, & Stepper, 1988). Therefore, regardless of the order between them, it is important to assume that emotion and cognition are distinct (Forgas, 1995) and emotional processes or effects are *not necessarily cognitively represented* even though they influence cognitive processes.

3 Situation Awareness and Driving

3.1 Cognitive Constructs and Situation Awareness

Driving is a multitasking activity that requires a driver to simultaneously manage various undertakings including primary, secondary, and tertiary tasks (Geiser, 1985; Kern & Schmidt, 2009). One of the widely used high-level cognitive models to explain such a dynamic situation is the situation awareness (SA) model (Endsley, 1995a). Situation awareness is, in brief, an understanding of the state of the environment including relevant parameters of the system (Endsley, 1995b). According to Endsley, decision-making and performance in complex, dynamic environments are dependent on the operator's situational awareness.

Endsley's (1995a) SA model illustrates three critical states of SA formation: *perception, comprehension*, and *projection*. Table 1 describes the relationship between these three levels of the situation awareness model and typical cognitive processes. Level 1 SA, perception, can be described in relation to attention and perception in traditional emotion research. Of course, attention may influence all three levels of SA, but it can be accounted for by similar mechanisms to perception and overall processing style in emotion literature. Level 2 SA, comprehension, can be described in relation to interpretation and judgment. Level 3 SA, projection, can also be described by judgment and decision-making. Decision-making is differentiated from the SA process in a narrow sense in Endsley's model. Based on this relationship, we can postulate plausible emotional effects on overall operator situation awareness as well as specific levels of situation awareness.

Table 1. *The Relationship between Situation Awareness Components in Endsley's (1995a) Model and Typical Cognitive Processes that Are Addressed in Emotion Literature*

Level of situation awareness	Sub-components of each level of SA	Typical cognitive processes
Level 1 SA, perception	The processes of monitoring, cue detection, and simple recognition	Attention & perception
Level 2 SA, comprehension	The processes of pattern recognition, interpretation, and evaluation	Interpretation & judgment
Level 3 SA, projection	Comprehension of the situation, and then extrapolating that information forward in time to determine how it will affect future states of the operational environment	Judgment & decision-making

3.2 Situation Awareness and Driving

Given that poor SA is a greater cause of accidents than improper speed or improper driving technique (Gugerty, 2011), there have been attempts to try to conceptualize driver SA and develop a driver situation awareness model (e.g., Gugerty, 2011; Ma & Kaber, 2005; Matthews, Bryant, Webb, & Harbluk, 2001). To illustrate, Matthews et al. have tried to propose a model for driver situation awareness that can be used as a basis for understanding the possible impact of the intelligent transportation systems on driving performance.

From the driving perspective, SA includes spatial awareness (i.e., an appreciation of the location of all relevant features of the environment), identity awareness (i.e., knowledge of salient items), temporal awareness (i.e., knowledge of the changing spatial picture over time), goal awareness (i.e., the highest goal may be the navigation plan to the destination; at a lower level, the maintenance of speed and direction to conform to the navigation plan; and at a still lower level, the need to maneuver and place the vehicle in an appropriate manner within the surrounding traffic stream), and system awareness (i.e., relevant information within the larger driving environment as a system). These aspects of SA have been integrated into a goal-oriented model of driver behavior that encompasses strategic, tactical, and operational goals of driving (Matthews et al., 2001; Ward, 2000). For instance, operational driving tasks (e.g., steering and braking responses) require level 1 SA. Tactical driving tasks require levels 1 and 2 SA to facilitate safe maneuvering of a vehicle in traffic by judging and comparing lane positions. Strategic tasks require level 3 SA for near-term projection of changes in the driving course and traffic patterns or for formulation of navigation plans.

On the other hand, Gugerty (2011) discussed situation awareness in driving with a focus on managing attention. His model involves three cognitive processes to update and maintain SA as knowledge: (1) automatic, preattentive processes that occur unconsciously and place almost no demands on cognitive resources; (2) recognition-primed decision processes that may be conscious for brief periods (< 1 second) and place few demands on cognitive resources; and (3) conscious, controlled processes that place heavy demands on cognitive resources. His model is conceptually different from Endsley's model. However, in practice, it compromises with Endsley's in that perceiving the elements of a situation (level 1 SA) is probably highly automated in most situations, whereas comprehension and projection (levels 2 and 3 SA) are more likely to use recognition-primed and controlled processes.

In addition to these attempts, there have been several empirical studies that try to engage SA in driving contexts. Walker, Stanton, and Young (2006) evaluated the effects of different forms of nonvisual vehicle feedback on driver SA using a probe–recall method. The findings confirm that the vehicle feedback (particularly auditory feedback) plays a key role in coupling drivers to the dynamics of their environment. An interesting result is that drivers demonstrated little awareness of diminished SA despite the large changes in vehicle feedback.

Other studies identified positive associations between SA and one or more dimensions of driving performance using various secondary tasks (Johannsdottir & Herdman, 2010; Ma & Kaber, 2005, 2007). For example, Ma and Kaber (2005) examined driver situation awareness involving an adaptive cruise control (ACC) system while calling on a cell phone. Results showed that the use of the ACC system improved overall driver SA under typical driving conditions, and reduced driver mental workload. However, the cell phone conversation (i.e., driving-irrelevant dialogue) degenerated driver SA (especially, levels 2 and 3 SA) and increased driver mental workload. The stage of perception (level 1 SA) may place relatively lower demands on human mental resources, as compared to comprehension (level 2 SA) and projection (level 3 SA), and consequently drivers may be able to address such demands even when resource competition occurs (Ma & Kaber, 2005). In a subsequent study, Ma and Kaber (2007) assessed the effects of in-vehicle navigation aids and reliability on driver SA and performance in a simulated navigation task. Results revealed that perfect navigation information generally improved driver SA and performance compared to unreliable navigation information and task-irrelevant information. They concluded that the in-vehicle automation appears to mediate the relationship of driver SA to performance in terms of operational and strategic behaviors. In summary, whereas research has shown the relationship between situation awareness and driver workload or automation, little research has addressed the relationship between situation awareness and driver emotion, which is a unique contribution of the current paper.

3.3 Situation Awareness Measurement in Dynamic Contexts

Situation awareness is a complex process that requires assessment by diverse online (during driving) and offline (post-driving) measures (Gugerty, 2011). Endsley (1995b) reviewed methodologies for the measurement of situation awareness in dynamic systems. As discussed earlier, performance and SA showed a positive correlation, but performance measures suffer from difficulty in diagnosis and lack of sensitivity. Alternatives to these measures have been brought forth, such as a freeze technique used in the SAGAT (Situation Awareness Global Assessment Technique; Endsley, 1995b, 2000) and the SPAM (Situation-Present Assessment Method; Durso et al., 1999; Durso et al., 1995). The SAGAT is an online query technique that taps an individual's recent memory of the situation. In the SAGAT, driving information on the display is removed and randomly selected questions are presented to the operator. The more queries correctly answered, the better is the operator's SA. In the SPAM, SAGAT-like queries are given to the operator, but information remains in view and response latency is used as the primary dependent measure. In these context-freeze techniques, SA queries have been frequently given during the task. Although these techniques are widely used, frequent queries may not be appropriate for the current study. First, providing queries may disrupt driving and influence the other measures as well. Second, frequent queries may enable drivers to concentrate more on driving behavior and even to memorize contextual information, which is not the case in an actual affective state. The presence of an assessment technique during driving is also likely to distract participants from the affective source and lead to deterioration of the meaning of the current experiment. Therefore, in the current experiment, SA was assessed with two types of techniques, one during driving and the other after the driving task.

The first SA measure was the implicit performance measure (e.g., Durso et al., 1999), which is operationally defined as the coping level with hazard events. Hazard perception has been considered as a way to measure situation awareness for dangerous situations in the traffic environment (Horswill & McKenna, 2004). Whereas empirical research has shown counterintuitive results stating that driving skill is not an important discriminatory variable for road safety (e.g., Williams & O'Neill, 1974), only drivers' hazard perception has been found to correlate with drivers' accident records. Researchers have widely used filmed traffic situations for a hazard perception test and asked participants to actively respond whenever they detect a traffic hazard, using a lever (e.g., Pelz & Krupat, 1974), button (e.g., McKenna & Crick, 1991), or touch screen (e.g., Hull & Christie, 1992). However, requiring such an active response from participants is different from the natural driving environment and in the current experiment it might distract participants from their affective source. Therefore, we used an implicit performance measure instead of obtaining explicit real-time responses. The driving scenario has ten events (see Table 3) that require a driver's attention and each event can be recognizable 3–5 seconds before it happens, so participants can predict the event in advance and respond appropriately. If the participants have good situation awareness at that moment, they are expected to cope with the situation effectively and appropriately.

Another measure is an offline questionnaire using an adaptation of the SAGAT. Endsley (1995b) once suggested that this type of post-test questionnaire would reliably capture the subject's SA at the end of the trial. Our offline query includes three different parts: (1) questions about the last driving scene, which measures SA; (2) questions about the whole driving, measuring driving-relevant, long-term memory; and (3) driving-irrelevant questions as a baseline. The recall-based queries (2) may be biased by participants' subjective recall ability and be arguable. However, in the same paper (Endsley, 1995b), the empirical results showed that the SA information is obtainable from long-term memory stores if schemata or other mechanisms are used to organize SA information. Thus, the SA information, which was clearly processed with respect to driving, may be able to remain longer (i.e., deep processing) than other irrelevant information (i.e., shallow processing).

4 Research Questions and Hypotheses

Recent empirical research (Jeon, Walker, & Yim, in press; Jeon et al., 2011) has shown that different discrete emotions might have specific effects on various measures of driving performance. Interestingly, however, these performance differences were not directly reflected at a conscious level in the measures, including subjective risk perception or perceived workload. This subtlety has motivated researchers to further investigate the relationship between emotions and driving in a more sophisticated way. In the current research, we attempt to examine emotional effects on driving performance, considering situation awareness as a medium between the two. This approach is expected to identify the roles and mechanisms of emotional effects in a dynamic environment more systematically. To test the possible specific effects, we focus on anger, one of the most critical emotional states in driving (e.g., Jeon & Walker, 2011). Once additional knowledge on the roles and mechanisms of the affective effects is accumulated, more effective intervention strategies can be determined about how to mitigate the affective effects on driving performance and safety.

In this research, we try to attain a deeper understanding of the effects of affective states on driver situation awareness and driving performance measures. More specifically, we are interested in the following two research questions:

1. Can we predict the emotional effects on driving performance based on drivers' self-awareness?
2. Can the situation awareness model provide an appropriate mechanism to explain the emotional effects on driving performance?

To answer these research questions, we conducted an experiment, in which young drivers (college students) drove in a simulator after either anger or neutral affect induction to examine whether the induced angry state influences drivers' situation awareness and driving performance as well as perceived workload and subjective judgment regarding their general driving. In addition to collecting various driving performance variables, the data on situation awareness were collected during driving (implicit performance) and in the end of the session (offline questionnaire) (Durso et al., 1999). As discussed, affective states have a considerable amount of impact on various cognitive states and these effects should be reflected on each level of the SA model, thereby the overall SA.

Here are our hypotheses for the experiment.

Hypothesis 1. *Anger will degrade driving performance more than neutral affect.*

Table 2. *Participant Information in Each Condition*

	No. of men	No. of women	Age	Years of driving
Anger	9	6	20.6	$M = 4.5$, $SD = 1.9$
Neutral	7	8	21.2	$M = 5.2$, $SD = 3.3$

There was no significant difference between the two conditions in terms of gender, age, and mean year of driving.

Hypothesis 2. *Anger will degrade driver situation awareness in terms of both implicit performance and the offline questionnaire as compared to neutral affect.*

Hypothesis 3. *Driving performance results will be positively correlated with situation awareness levels.*

Hypothesis 4. *Subjective judgment on general driving behavior after anger induction will not be different from that of the neutral state (based on Jeon et al., in press; Jeon et al., 2011).*

Hypothesis 5. *Perceived workload of the angry state will not be different from that of the neutral state (based on Jeon et al., in press; Jeon et al., 2011).*

5 Experiment

5.1 Method

5.1.1 Participants. Of the 35 undergraduate students who registered for the study, five (14%) participants showed symptoms of simulation sickness in the screening protocol (Gable & Walker, 2013), so they were excused from the remaining experimental procedure. Thus, 30 participants (see Table 2 for details) completed the experiment for partial credit in psychology courses. They reported normal or corrected-to-normal vision and hearing, and provided informed consent and demographic details about age, gender, and years of driving. All participants were required to have a driver's license and more than two years of driving experience to control for any effects of novice drivers. Therefore, all of the participants could be categorized as an "advanced apprentice/junior journeyman" group in terms of driving experience level (Durso & Dattel, 2006). For the purpose of the study, participants were not clearly informed about the goal of the study, but they were debriefed after the experiment. In the debriefing session, they were told about an impact of induced anger and plausible risks.

Figure 1. *View of the driving simulator. Each participant drove the same pre-defined route.*

5.1.2 Apparatus. Figure 1 shows a mid-fidelity National Advanced Driving Simulator (NADS) MiniSim version 1.8.3.3. The simulation software runs on a single computer, running Microsoft Windows 7 Pro on an Intel Core i7 processor, 3.07 GHz and 12 GB of RAM, and relays sound through a 2.1 audio system. Three Panasonic TH-42PH2014 42″ plasma displays, each with a 1280 × 800 pixel resolution, allow for a total of 130° field of view in front of the seated participant. The center monitor is 28 inches from the center of the steering wheel and the left and right monitors are 37 inches from the center of the steering wheel. The MiniSim also includes a steering wheel, adjustable car seat, gear-shift, and gas and brake pedals, as well as a Toshiba Ltd. WXGA TFT LCD monitor with a 1280 × 800 resolution to display the speedometer, etc. Environmental sound effects are also played through two embedded speakers. These sounds included engine noise, brake screech, turn indicators, collisions, etc. In the present experiment, all participants experienced the same predefined route and properties for the driving task.

Table 3. *Hazard Events in the Driving Scenario*

Predictable hazard events
Event 1. Car crosses over center line into driver's lane
Event 2. Motorcycle pulls into driver's lane
Event 3. Traffic signal suddenly changes to yellow in the intersection
Event 4. Car U-turns in front of driver
Event 5. Boy runs out from behind a parked car
Event 6. Car pulls into road ahead of driver
Event 7. Truck suddenly appears in highway entrance
Event 8. Construction and lane merge
Event 9. Two deer cross road
Event 10. Car entering highway cuts off driver

5.1.3 Driving Scenario. A driving scenario was created using the iSAT software, which comes with the NADS MiniSim. The scenario included an urban road (with speed limit 40 mph) and a highway (with speed limit 50–65 mph). Also, it contained various road signs and vehicles, traffic signals, and pedestrians commonly seen in an actual driving environment. Ten different hazard events (see Table 3) were created in the scenario to measure driver situation awareness. Those events occurred approximately every minute, beginning a minute after the start of the drive.

5.1.4 Design and Procedure. Prior to any data collection, the protocol for this study was submitted to and accepted by the Georgia Tech Institutional Review Board ethical committee. This review included a submission of all study materials and protocols and was necessary to be cleared by the committee before starting the study, particularly in this case due to the manipulation of emotions. Participants were first asked to complete a consent form and then given instructions of what the study would entail. Participants were then asked to rate their current affective states using seven-point Likert-type scales (1: not feel at all $\sim$ 7: strongly feel). The affective states included nine discrete adjectives that were reported as important affective states in driving contexts: fearful, happy, angry, depressed, confused, embarrassed, urgent, bored, and relieved (e.g., Ashley, 2001; Eyben et al., 2010; Jackson et al., 2013; Jones & Jonsson, 2008; Li & Ji, 2005; Lisseti & Nasoz, 2005; for empirical factor extraction, see Jeon & Walker, 2011). Then, participants went through the Georgia Tech Simulator Sickness Screening Protocol (Gable & Walker, 2013) where they were asked to: (1) rate their current physical feelings on 17 categories using an 11-point Likert-type scales (0: not feel at all $\sim$ 10: strongly feel); (2) drive a two-minute city driving scenario in the simulator (different from the scenario used in the actual experiment); and (3) rate their physical feelings again on the same questionnaire. If the participants felt any symptoms of simulator sickness (e.g., light-headed, dizzy, or other adverse reaction) at any time during the drive, the simulation was stopped and they were excused from testing. They were also excused from testing if their scores showed signs of simulator sickness (i.e., if any number is greater than or equal to 5 more than the pre-drive survey, or if any three of the ratings are above 3 as compared to the pre-drive survey, adapted from Gianaros, Muth, Mordkoff, Levine, & Stern, 2001).

Participants who had not shown evidence of simulator sickness continued into the actual experimental task. These participants were randomly assigned to either the anger or neutral emotion condition. To induce a particular affective state, participants had 12 minutes to write a description of a past emotional experience, which is a frequently used affect induction methodology (e.g., Bodenhausen, Sheppard, & Kramer, 1994; Ellsworth & Smith, 1988). Moreover, a recent study shows that this is the most effective among other affect induction methods (Lobbestael, Arnttz, & Wiers, 2007). An experimenter instructed them to remember the memory as clearly as possible and to emotionally revisit the experience again. Participants in the anger condition were urged to refer to two sample paragraphs (Bodenhausen et al., 1994; Jeon et al., in press) in the instruction sheet to help them write their own paragraphs. One of these was related to driving as shown in the following:

> ". . .I was already late for the meeting when I woke up. I quickly packed all resources I organized last

> night and drove my car in a hurry. But after a while, a huge truck blocked the road and a series of cars were waiting for that truck to make a U-turn. I saw there was not enough space for the truck and all cars had to back up, one by one, to make more space during the already hectic morning hours. It was a disaster!" (Anger)

If participants had more than one experience to write about, they could choose to write about all of them within the time provided. Participants in the neutral affect condition wrote a description of the mundane events of the previous day (Bodenhausen et al., 1994; Jeon et al., 2011).

After writing the mood-induction paragraphs, participants completed a second rating of their affective states and then answered subjective judgment questions regarding driving competence and risk perception (e.g., Dorn & Matthews, 1995) using seven-point Likert-type scales: (1) How do you feel about your confidence level for driving? (2) How much do you feel accident risk in your driving? (3) Do you think your driving is safer than other drivers who are your same age and gender?

After these questionnaires, participants drove the predefined scenario, which lasted approximately 13 minutes. They were instructed to drive as they would drive in the real world, following any traffic and safety rules. Through the driving course, participants drove on the same road except for one left turn, which the experimenter announced in advance. Immediately after the drive, participants were asked to answer the offline SA assessment questionnaire. After filling out the SA questionnaire, participants completed the third affective state rating. Finally, they filled out the electronic version of the NASA-TLX (Hart, 2006) to provide measurements of perceived workload for the overall driving task, and a short questionnaire for demographic information and comments regarding the study. All the participants were then debriefed on the study, and about possible residual effects of emotions on their real-world driving. Additional data collected included number of errors committed while driving, as recorded by a trained experimenter, and how the drivers coped with hazard events. These observed data served as implicit measures of driver SA. Meanwhile, driving performance data were also logged by the driving simulator.

5.1.5 Dependent Variables for Driving Performance. Driving performance data were collected (1) manually by a real-time judge who was present at all times, and (2) by system logging:

1. *Manually recorded observer's log*: During the drive, a trained experimenter recorded the number of all driving errors, as well as the coping level with the ten hazard events, as an implicit performance measure for driver SA. The coping level for each event was scored as 0: smooth management; 1: near accident with brake screech sound; or 2: crash with objects (thus, their overall implicit performance scores across ten events could range from 0: best to 20: worst). Manually counted number of errors included four general driving performance measures that anger has been shown to influence negatively (e.g., Dula, Martin, Fox, & Leonard, 2011; Jeon et al., in press; Jeon et al., 2011). Specifically, crossing the centerline and sideline were combined into "Lane Deviation." (LD). Infractions of red lights and failure to use turn signals were categorized under "Traffic Rules" (TR). Violations of the speed limit were named "Over Speed" (OS), and collisions were named "Collision" (CO). These variables were chosen because anger easily leads to aggressive behaviors and these aggressive behaviors in driving situations often cause road rage (Burns & Katovich, 2003).
2. *Automatically recorded system log*: Additional driving performance data were automatically logged in the driving simulator. These data included five driving performance categories: Lane Deviation (deviation of the center of the vehicle from the center of the road in feet), Speed, Steering Wheel Angle, Brake Pedal Force, and Collision. The first four variables contained various calculated values such as average, standard deviation, maximum, and minimum. Lane Deviation also included the number of lane crossings.

Other driving tasks such as the lane-change-test (Mattes, 2003) or headway distance measures (e.g., Ma

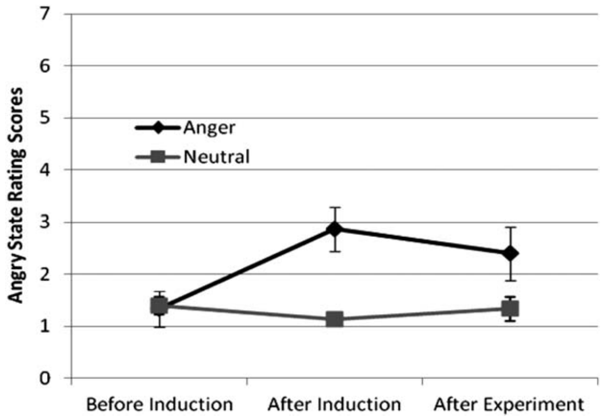

Figure 2. *Anger rating scores across rating timings. In the anger condition, the anger score after induction was higher than the score before induction. Also, the score after the experiment was higher than the score before induction. For the neutral condition, there was no significant change in the anger rating scores. Error bars indicate standard error of the mean.*

& Kaber, 2005) were not used in this study because participants might concentrate more on those tasks, being distracted from their affective source.

5.2 Results

5.2.1 Manipulation Checks. We assumed that the participants were equal due to their random placement in conditions. As Figure 2 shows, there was no difference in their initial angry state. Moreover, there was no significant difference in any emotional state between the two groups before induction.

Participants' writings about past experiences were congruent with previous research (Ellsworth & Smith, 1988; Smith & Ellsworth, 1985). Overall, participants in the angry state tended to describe events related to "other-responsibility" and "individual control," including conflict with colleagues (4 participants), frustration at parents (1), failed tasks or bad jobs (5), lost chances or personal belongings (3), and road rage (2). For the neutral condition, participants described just daily activities such as driving or walking (6), getting ready in the morning/for bed (2), grocery shopping (1), and other routines (6), which are also in accordance with previous research (Jeon et al., 2011).

Figure 2 shows the overall mean rating of angry states at the three times. Results were analyzed with a separate repeated measures analysis of variance (ANOVA) for each affective condition. An ANOVA result revealed a statistically significant difference among the three timings for anger: $F(2, 28) = 4.41$, $p < .05$, $\eta_p^2 = .24$. For the multiple comparisons among the three timings for anger, paired samples t-tests were conducted. For multiple comparisons of within-subjects conditions, we can use either Bonferroni or Scheffe (Keppel & Wickens, 2004). Bonferroni is used when forming the contrasts without looking at the means. When researchers have already peeked at the means, which is our case, Scheffe's procedure is used. For both, the calculations are the same, but only for Bonferroni, a corrected α level is used. We kept using $\alpha = .05$ based on Scheffe's for further multiple comparisons. The anger score after induction ($M = 2.87$, $SD = 1.6$) was higher than before induction ($M = 1.33$, $SD = 1.3$, $t(14) = -2.88$, $p < .05$). The anger score after the experiment ($M = 2.40$, $SD = 1.9$) numerically decreased from its peak, $t(14) = 1.10$, $p > .05$, which was numerically higher than before induction, $t(14) = -1.74$, $p = .10$. For the neutral condition, the change of participants' angry state was also analyzed. Participants in the neutral condition showed no significant change among the three timings for anger.

In short, the intended anger level increased after the induction procedure and decreased while driving. Even after the experimental procedure (around 15–20 minutes), induced anger seemed to still remain high.

5.2.2 Driving Performance. As reported, driving performance data were collected in the two ways: manual log and system log, and both of them showed significant differences between the two conditions.

1. *Manual log*: Figure 3 shows overall driving performance aggregated across four categories in both affective states. Participants in the anger condition ($M = 9.53$, $SD = 3.6$) showed significantly more errors than those in the neutral condition ($M = 5.67$, $SD = 3.0$, $t(28) = 3.19$, $p < .01$). Figure 4 shows the number of driving errors according to error type in both affective states, which indicates that participants in the anger condition consistently

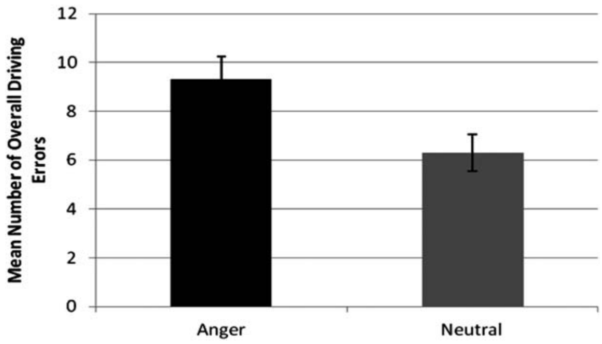

Figure 3. *Number of overall driving errors in both affective states (manual log). Anger led to significantly more errors than neutral. Error bars indicate standard error of the mean.*

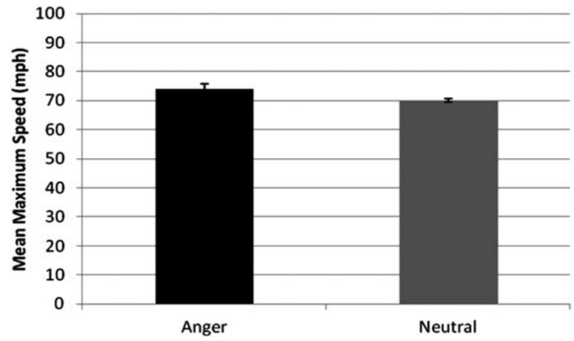

Figure 5. *Maximum speed in both affective states (system log). Anger led to significantly higher maximum speed than neutral. Error bars indicate standard error of the mean.*

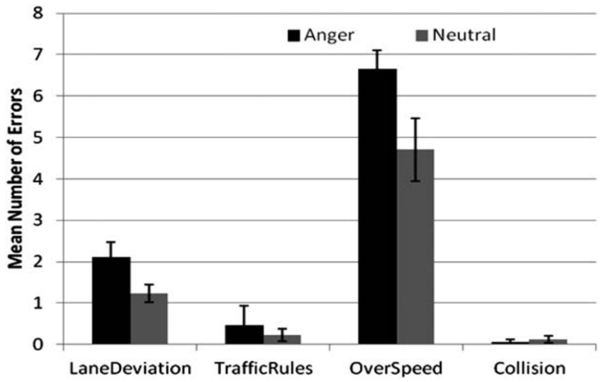

Figure 4. *Number of errors according to error type in both affective states (manual log). Error bars indicate standard error of the mean.*

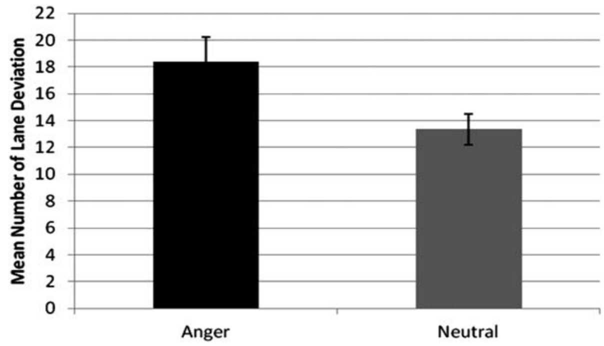

Figure 6. *Number of lane deviation times in both affective states (system log). Anger showed significantly more lane deviation times than neutral. Error bars indicate standard error of the mean.*

made more errors in the neutral condition except for the number of collisions. For each type of driving errors, independent sample *t*-tests revealed that the participants in the angry state ($M = 2.13$, $SD = 1.4$) made significantly more lane deviation times than in the neutral state ($M = 1.00$, $SD = 0.8$, $t(28) = 2.75$, $p = .01$). Additionally, the participants in the angry state ($M = 6.80$, $SD = 1.8$) made a significantly higher number of over speed errors than in the neutral state ($M = 4.27$, $SD = 2.9$, $t(28) = 2.87$, $p < .001$).

2. *System log*: Figure 5 shows the mean maximum speed in both affective states. Participants in the anger condition ($M = 74.11$, $SD = 6.0$) had a significantly higher maximum speed than neutral participants ($M = 70.05$, $SD = 2.3$, $t(28) = 2.44$, $p < .05$). Figure 6 shows the mean number of lane deviation times. Again, participants in the anger condition ($M = 18.4$, $SD = 7.0$) had a significantly higher number of lane deviation times than neutral participants ($M = 13.3$, $SD = 4.1$, $t(28) = 2.45$, $p < .05$). There was no other variable to show a significant difference between the two conditions.

These consistent results were confirmed by highly positive correlations between the manual log data and the system log data (lane deviation with lane deviation times, $r = .53$, $p = .002$, with average lane deviation, $r = .46$, $p < .05$, with *SD* of lane deviation, $r = .62$, $p < .001$; over speed with average speed, $r = .68$, $p < .001$, with maximum speed, $r = .57$, $p = .001$; collisions with collisions, $r = .32$, $p = .092$).

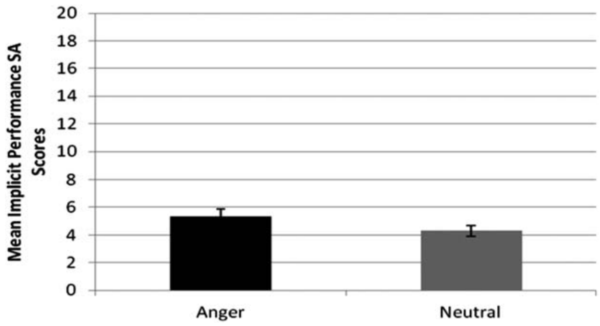

Figure 7. *Implicit performance SA scores in both affective states. In the anger condition, the score was significantly higher than in the neutral condition, which means anger degrades driver situation awareness more. Error bars indicate standard error of the mean.*

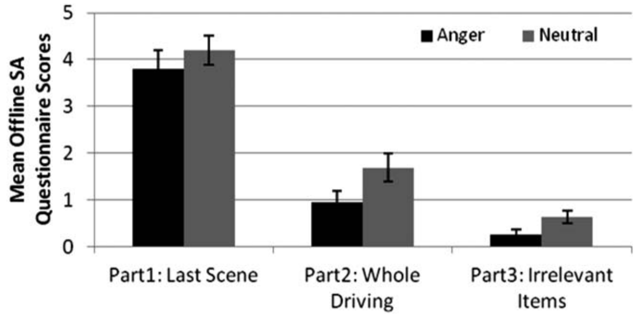

Figure 8. *Offline SA questionnaire scores in both affective states. In the anger condition, the scores were lower than in the neutral condition, which means anger degrades driver situation awareness more. Error bars indicate standard error of the mean.*

To ensure that no other variables influenced the performance results, the results for gender and driving experience were also analyzed. For gender, there was no significantly different number of errors between women ($N = 14$) ($M = 6.43$, $SD = 2.7$) and men ($N = 16$) ($M = 8.86$, $SD = 4.4$). For driving experience, years of driving did not show a significant correlation with the number of driving errors. However, years of driving showed a significantly negative correlation with the maximum speed ($r = -.41$, $p < .05$) and the brake pedal force standard deviation ($r = -.45$, $p < .05$). In other words, more experienced drivers were not likely to drive with higher speed and showed more reliable brake pedal force. However, these differences did not bias either condition in the study because there was no significant difference in years of driving between the anger condition ($M = 4.46$, $SD = 1.9$) and the neutral condition ($M = 5.23$, $SD = 3.3$).

5.2.3 Situation Awareness. For the SA scores, results were analyzed using independent samples t-tests for both implicit performance and offline questionnaire scores. Note that a higher score in the implicit performance measure means worse situation awareness, whereas a higher score in the offline questionnaire means better situation awareness. Figure 7 shows the mean implicit performance scores in both affective states. Those with induced anger ($M = 5.4$, $SD = 2.0$) had significantly higher scores than neutral participants ($M = 4.0$, $SD = 1.6$, $t(28) = 2.12$, $p < .05$), which means that participants in the angry state had lower driver situation awareness than in the neutral state. Figure 8 shows the mean offline questionnaire scores. Overall, in all three parts of the questionnaire, participants in the anger condition gained lower scores than participants in the neutral condition, which means lower situation awareness. In questions about (1) the last driving scene (operationally defined as SA, here), angry participants ($M = 3.8$, $SD = 1.5$) had lower scores than those in the neutral condition ($M = 4.2$, $SD = 1.2$), but it was not statistically reliable: $t(28) = -.798$, $p > .05$. In questions about (2) the whole driving, angry participants ($M = 0.9$, $SD = 0.9$) had marginally lower scores than participants in the neutral condition ($M = 1.7$, $SD = 1.2$, $t(28) = -1.90$, $p = .068$). In questions about (3) driving-irrelevant items, those in the angry condition ($M = 0.3$, $SD = 0.4$) had significantly lower scores than neutral participants ($M = 0.6$, $SD = 0.5$, $t(28) = -2.21$, $p < .05$).

Implicit performance SA scores significantly positively correlated with the number of errors in the manual log ($r = .37$, $p < .05$). There were no significantly different implicit performance SA scores between women ($M = 4.29$, $SD = 1.9$) and men ($M = 5.13$, $SD = 2.1$). Also, years of driving did not show a significant correlation with situation awareness scores. There was no correlation between the amount of increased angry state and situation awareness or performance (Jeon et al., 2011). In other words, overall, angry drivers show worse situation awareness and more driving errors on average, but the change in the self-rating score cannot predict driver situation awareness or driving performance.

5.2.4 Subjective Judgment. For the subjective judgment rating scores across the affective states, results were analyzed with independent sample *t*-tests for each question. Overall, no comparison led to statistically significant results on subjective judgment ratings.

5.2.5 Perceived Workload. For the overall perceived workload scores, independent sample *t*-tests also showed no difference between the two affective states, which means there is no significantly different perceived workload resulting from an angry state.

5.3 Discussion

Our experiment compared diverse variables including driving performance, situation awareness, subjective judgment, and perceived workload in the induced angry state with those in the neutral state. The overall results demonstrated that induced anger can degenerate driver situation awareness and driving performance. However, it did not significantly influence either the subjective judgment or the overall perceived workload, which might imply that the effects created by the anger occurred under participants' conscious level.

5.3.1 Affect Induction. Having participants write about their past experience seems to be successful in terms of anger induction. It was found that the induced anger decreased as the experiment went on, but a certain amount of anger still remained after the experiment, which accounts for the source of different outcomes between the two emotion conditions. Self-rating alone might not be a sufficient method to measure participants' emotional change. For example, participants can rate their state as what they are supposed to be. There might be some individual differences with respect to rating the relative strength of their emotional change. Nevertheless, self-rating is one of the standardized affect measures in the domain (Helander & Khalid, 2006; Mauss, & Robinson, 2009) to provide sufficient psychological evidence about discrete emotional states. To measure emotional changes more accurately, we are currently using other physiological tools together (e.g., Jansen et al., 2013).

In the traditional lab studies, psychologists have used diverse emotion-priming methodologies, such as watching photos (Lang, Bradley, & Cuthbert, 1990) or film clips (e.g., Fredrickson & Branigan, 2005), reading scenarios or stories (e.g., Johnson & Tversky, 1983; Raghunathan & Pham, 1999), listening to music (e.g., Jefferies, Smilek, Eich, & Enns, 2008; Rowe, Hirsh, & Anderson, 2007), or writing down their past experience (e.g., Gasper & Clore, 2002). On the other hand, driving researchers have tried to devise some hazard events so that drivers got frustrated (i.e., integral affect) in those scenarios (e.g., Harris & Nass, 2011; Lee, 2010).

In this experiment, we used both incidental (i.e., task-irrelevant) and integral (i.e., task-relevant) affect priming. "Writing personal experiences" was used as incidental affect induction, specifically because anger needs a clear opponent or source of affect. In this aspect, looking at photos or watching film clips might not be sufficient to induce anger. Moreover, because driving is a much more complicated and longer-lasting task than a simple social judgment or decision-making task, the strength and duration of induced affective states are expected to be more important and have a greater influence on driving performance. Therefore, this experiment also included some hazard events in the scenario as a source of integral affect. The results support that the multiple emotion-priming methods used in the current experiment work well for this type of emotional driving study. Using both incidental and integral affect may make our experiment more similar to the real situation.

Note that it is debatable whether the induced affective states in a driving simulator are equivalent to affective states in actual driving. The affective effects in the actual driving context might be different (or larger) than in the simulator. However, the significant results of the current simulation study demonstrate that there is necessity for further research. In addition, we have the following features in our simulation environment that literature points out as components to make a virtual environment more similar to the real world: (1) three-dimensional viewing (vs. 2-D); (2) dynamicity in terms of time perception (vs. static images); (3) closed-loop interaction (vs. open loop) (e.g., Carignan & Cleary, 2000): there is little delay from the time the action is initiated until motion occurs; (4) egocentric frame of references (vs. exocentric view) (McCormick, Wickens, Banks, & Yeh, 1998; Peterson, Wells, Furness, & Hunt, 1998); and (5) multimodal interaction (vs. unimodal interaction) (Werkhoven & Groen, 1998). As discussed in Method (Section 5.1), our simulator has visual, auditory, and tactile/haptic feedback (e.g., steering, brake and gas pedals). Therefore, we assume that our participants had "sufficient information" about the task environment in terms of the sensory-motor system simulation about virtual presence (Sheridan, 1992) and ecological validity (i.e., similarity of perceptual stimuli; see Hammond, 1998). If we have physical forces on the whole body when accelerating or stopping, it would be more helpful in terms of participants' immersion.

Even though our participants were aware of their anger (at least incidental anger from their own writing), they seemed not to notice or predict the "effects" of anger on their driving as shown in their subjective judgment or perceived workload.

5.3.2 Driving Performance. Angry participants "consistently" showed more errors than neutral participants in most error types. From this experiment, specific anger effects on driving variables were clearly confirmed including over speed, more lane deviations, and more infractions of traffic rules, which is consistent with literature (Deffenbacher et al., 2003; Jeon et al., 2011; Stephens & Groeger, 2008; Underwood et al., 1999). All of these components make their driving more risky and are likely to lead to fatal outcomes when integrated with other situations in real driving. Most previous research has shown these effects based on the survey instrument depending on participants' memory about their own behavioral patterns and *traits* (e.g., Deffenbacher et al., 2003; Nesbit & Conger, 2012). However, the current study confirms those results with empirical driving and induced affect *state*. This state–anger research will be more useful in terms of policy making and prevention technology development (Abdu, Shinar, & Meiran, 2012).

Research has shown that participants who are asked to do dual tasks while driving intuitively adopt an adaptive behavior in order to perform the secondary task (Chen & Lin, 2003; Gugerty, Rando, Rakauskas, Brooks, & Olson, 2003; Tchankue, Wesson, & Vogts, 2011). For example, Chen and Lin (2003) showed that participants compensated for the increased reaction time by increasing the headway distance to the lead car and decreasing speed during the dual-task scenario (driving and talking) using a hands-free cell phone. In the present experiment, however, participants did not show such a tendency to make up for their degenerated performance. Participants with anger consistently drove faster, showed more lane deviation, and violated rules and signals more than participants with neutral. Because they did not notice the "effects" of their affective state on their driving, they seemed to lack compensational strategies. Drivers' lack of awareness of emotional effects on driving performance might make emotional driving more dangerous compared to driving with secondary tasks. To objectively assess it, we are currently comparing the effects of emotions with the effects of secondary tasks on driving performance in a single study.

5.3.3 Situation Awareness. As expected, driver situation awareness was degenerated by induced anger, especially when measured using implicit performance. Offline questionnaire results showed a similar pattern, but did not lead to a statistically significant difference in part 1, which was intended to measure driver SA. It seems that the one-time survey may not be sufficient to obtain enough statistical power. As discussed earlier, the SAGAT or the SPAM *frequently* asks participants about their situation awareness to get sufficient data. One interesting result is that the participants in the anger condition also showed lower scores than in the neutral condition in part 3, questions of which were not related to a primary driving task, such as restaurant names and signs. It was originally hypothesized that participants in both groups would be similarly bad at answering those task-irrelevant items. Due to this unexpected different result in part 3, however, it became less clear whether better results of the neutral participants in part 1 and part 2 came from different processing levels and memory, or came from just different response attitudes toward any questions based on their affective states.

Situation awareness scores were positively correlated with some of the driving performance measures as hypothesized. Therefore, one can infer that the anger might decrease driver situation awareness, which degenerates driving performance in turn. However, in order to identify a clear causal relationship, further research is required with more participants (e.g., a mediation model among emotion, SA, and performance measures).

Based on the present results, it is difficult to say that the coping level of hazard events corresponds to driving techniques or experience. First of all, years of driving did not show a significant correlation with situation awareness scores, nor with driving performance. In addition, driving literature has usually reported that nine to ten years of difference is needed to make significantly different performance levels between participants (e.g., Durso & Dattel, 2006). There was no difference in years of driving between the two conditions in the current experiment.

For the original purpose of this study, the relationship between emotional processes and situation awareness and its effects on driving performance can be further disentangled in terms of more theoretical aspects. Endsley and her colleagues (Endsley, Bolte, & Jones, 2003) classified SA demons—the enemies of situation awareness, as follows: attention tunneling, requisite memory trap, workload, anxiety, fatigue, and other stressors (WAFOS), data overload, misplaced salience, complexity creep, errant mental models, and out-of-loop syndrome. Based on the identical results between the two conditions, *workload* can be eliminated from the current discussion. Among the remaining others, it seems reasonable to focus on delineating *attentional tunneling* as the anger effects on situation awareness with respect to our experiment.

Constant juggling of different aspects of the environment is a key factor for successful SA. Unfortunately, people can often get trapped in a phenomenon called attentional tunneling (Baddeley, 1972; Broadbent, 1954), in which people lock in on certain aspects or features of the environment they are trying to process, and will either intentionally or inadvertently drop their scanning behavior. Even though drivers can consistently scan their environment, it does not necessarily mean that the information at that location is processed. Such instances resulting from a failure of divided attention has also been called *inattentional blindness* and has been widely explored in laboratory studies (Simons & Chabris, 1999). In either case, drivers cannot maintain good SA. These types of attentional issues can arise from affective sources, which are assumed to happen in the current experiment. *Rumination* is one of the cognitive demands or resource misallocations created by affective sources (Beal, Weiss, Barros, & MacDermid, 2005). It is defined as "a class of conscious thoughts that revolve around a common instrumental theme and that recur in the absence of immediate environmental demands requiring the thoughts" (p. 7). According to Berkowitz (1989), goal blockage that is common to *ruminative* thought frequently precedes an affective response such as frustration, anger, or anxiety. Moreover, if the cause of the affective state is unrelated to the current performance episode (i.e., incidental affect, which is also the case in the current experiment), continued ruminative thoughts should serve as an additional cognitive demand that interferes with task performance (Beal et al., 2005).

This successive chain can also be well explained by the framework, "presence" (Sheridan, 1992). It is worth noting that researchers have used a *space metaphor* about presence, such as "being there" (Minsky, 1980) and "feeling of being present in an environment other than one the person is actually in" (Sheridan, 1992). We interpret that our participants felt a type of presence or immersion into their past experience after they wrote their emotional memory. Because their attention was captured in that past *virtual space* (i.e., rumination), they showed a type of inattentional blindness in the present driving environment. This also corresponds to other driving literature, which shows that the deficits with the secondary tasks are due to engaging other cognitive *contexts*, not due to physical activities (Strayer & Johnston, 2001). In other words, participants sat in the driving simulator *physically*, but they might have visited their past experience environment *mentally*. Consequently, their SA about the current driving environment was degraded. They seemed to assess their driving environment superficially (Stephens, Trawley, Madigan, & Groeger, 2012).

In summary, induced anger yielded rumination due to participants' immersion in the emotional context, which led to attentional tunneling or inattentional blindness so that drivers did not develop complete and accurate knowledge of driving environments and vehicle states (i.e., situation awareness), and thereby driving performance was degenerated.

5.3.4 Subjective Judgment. Given that subjective judgment scales showed no difference between the anger and the neutral conditions, we can conclude that their conscious responses did not reflect any anger effects. Based on their affect rating scores, we can assume that participants might feel a certain level of anger after affect induction. However, those subject feelings might not influence their judgment about their confidence, safety, or risk level in the context of driving. As a result, they did not compensate for their performance decrease in driving. In other words, participants seemed to fail to link their affective state and their behavioral changes.

People generally do not know well what they are feeling (even though they think they are well aware of it) (Picard, 2010). Affect research has shown that even just awareness of the *source* of one's affective state can make the person less influenced by those affective states (Tiedens & Linton, 2001). This can support the necessity of an affect detection and regulation system for drivers (Eyben et al., 2010). Objectively carried information on a driver's current affective state can be powerful and can facilitate driver situation awareness by awakening them from their affective source.

5.3.5 Perceived Workload. It is an important finding that there was no significant difference in perceived workload between the two conditions. It strongly supports that affective effects are independent of *consciously* perceived workload. Then, it might imply that emotion research needs a different approach or framework from the workload research tradition. It would be prudent to measure objective workload in an effort to determine if it is simply *subjective* workload that is not affected by anger or if *objective* measures of workload show a similar result. To this end, our on-going study is using functional Near-Infrared Spectroscopy (fNIRS) (Derosière, Mandrick, Dray, Ward, & Perrey, 2013) for objective workload measure. If performance degeneration in the angry state is not because of workload, there should be other mechanisms that need to be identified further.

6 Conclusions and Future Work

The present study investigated the mechanism of the consciously unnoticeable emotional effects on driving performance. Results showed that situation awareness could be a conduit between the angry state and reduced driving performance. Our experiment also supported that the presence of anger did not influence their conscious risk perception and subjective workload scores. Given that angry participants did not show any compensation for their degenerated driving performance, affective effects might be more serious than the effects of secondary tasks, for which a driver is likely to show some adaptive compensation strategies.

In this study, the emotional effects on performance in a dynamic situation were more deeply explored by integrating the construct of situation awareness, whereas more research is needed to show a clearer causal relationship among those constructs (see Jeon, 2012a). If situation awareness is a critical medium between a drivers' emotional state and driving performance, then we could try to devise intervention strategies to increase driver situation awareness in addition to regulating drivers' emotional state. It would also be a good research question whether we need to use subliminal cues (e.g., music [Jeon, 2012b], smell, etc.) as an intervention for emotional drivers given that driving is a highly demanding task.

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