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Differences in Stress-level and Attentional Functions of Experienced and Novice Drivers in Hazard Situations

위험 상황 하 운전자 경험에 따른

스트레스 수준 및 주의 능력 차이 비교

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Abstract

Differences in Stress-level and Attentional Functions of Experienced and Novice Drivers in Hazard Situations

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The purpose of this study is to determine the differences in stress-level and attentional functions between experienced and non-experienced drivers during intersection-related hazard situations. A simulation experiment was conducted to twenty-one licensed drivers (15 males and 6 females, mean age 27.71 ± 3.62) which were categorized into two groups, experienced and novice, based on the frequency and length of their driving experience. The participants were asked to drive on the same lane at a constant speed for 9 randomized trials with three different conditions (no hazard, low hazard, high hazard). ECG, GSR and eye-tracking data were collected throughout the whole session and a subjective questionnaire measuring perceived stress and attention load was administered after every trial. Mixed-ANOVA showed significant variations in driving performance across conditions ($p < 0.001$ for both lane and speed deviation), but not in between groups. Similarly, GSR metrics (SCR, Sum of Amplitudes, Phasic Max) showed a progressive increase in stress from hazard conditions 1 to 3, but no differences were found between groups. In contrast, ECG measures (STD RR, RMSSD, HF) revealed that experienced drivers exhibited greater stress during intersection-related hazard situations than novices. In terms of attention, both AOI-based and non-AOI-based measures (fixation count, mean fixation duration, time-to-first-fixation and horizontal dispersion) demonstrate significant differences in attention functions across conditions, but group effects were only evident in time-to-first fixation metrics. It was revealed that experienced drivers were faster to attend to the hazard stimulus than novices. In addition, an interaction was also found between experience and condition in mean fixation duration. Experienced drivers showed proportional attention allocation to both the primary task and hazard stimulus during high hazard situations than novice drivers. The overall result of the psychophysiological measures was further affirmed by the results from the subjective questionnaire whereby experienced drivers exhibited more changes in stress-level and attention load as the condition changed. The results suggest that experienced drivers are more sensitive, in terms of stress and attention functions, to changes in driving conditions than novices. The results of this study may be applied in designing more effective training modules and driver support systems that would help drivers specifically during intersection-related hazard situations.

Keywords: Driving Experience, Stress, Attention, Biosignal

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Chapter 1

Introduction

1.1 Background

Safety has always been one of the main concerns in driving research. Every year about 1.35 million people die in road accidents worldwide, approximately 3,700 deaths a day, making it the 8th leading cause of death globally (World Health Organization, 2018). In particular, traffic statistics show that intersection-related accidents are becoming more of a concern as it accounts for roughly 50% of all traffic injuries and more than 20% of all traffic fatalities over the past several years (US Department of Transportation, 2010). The report also showed that 96.1% of these intersection-related accidents are attributed to driver error. Driver's failure to correctly recognize or assess the hazard involved in the situation is seen to be one of the biggest contributing factors for these mishaps. These data suggest that despite the abundance of literature in safe driving, there may still be a lack of understanding as to how and why such errors occur in this certain type of driving situation. Thus, in order to reduce such occurrences, it is imperative to conduct a thorough investigation regarding how driver-related attributes affect their driving performance in intersection-related hazard situations.

Lack of driving experience is seen as one of the leading causes of driver attributed errors. Several studies have shown how lack of experience contributed to poor driving performance (Lansdown, 2002; Yang, Jaeger & Mourant, 2006) and increased chances of road accidents (Liu, 2009; McKnight and McKnight, 2003). On a similar note, traffic statistics have also shown an overrepresentation of young novice drivers in road accidents (Horswill and McKenna 2004). Studies comparing experienced and novice drivers have found that novice drivers are more prone to mishaps because of the poorer attention allocation (Pemmer et al., 2018), weaker hazard anticipation (Zhang et al., 2019, Smith et al., 2009; Lee et al., 2008; Fisher et al, 2007; McKnight and McKnight, 2003; Garay et al., 2004), and increased vulnerability to external stressors (Li et al., 2019, Nabatilan et al., 2011). Experienced drivers, on the other hand, are believed to be less prone to accidents because they have an adequate mental model for driving (Horswill and McKenna, 2004), wider attention allocation (Bruder and Hasse, 2019; Lehtonen et al., 2014), efficient hazard scanning and anticipation (Beanland and Wynne, 2019, Zhang et al., 2019), and are less susceptible to stress while driving (Li et al., 2019). Although driving as a task can be easily learned even within several hours (Hall and West, 1996), higher-order skills are still necessary for safe driving. Since limited experience may be associated with the lack of higher-order perceptual, cognitive and psychomotor skills critical for safe driving, it is crucial to identify and inspect which specific attributes contribute to such shortcomings.

Two of the most noteworthy attributes that cause driving errors that may set experienced and novice drivers apart are their susceptibility to stress and overall attentional function. In general, several studies have already proved how heightened stress (Duncliff et al., 2019; Katasis et al., 2015) and inattention (US Department of Transportation, 2010) can be detrimental to safety in driving. Based on the previous report, a huge portion of intersection-related accidents are attributed to driver's decision and recognition error (US Department of Transportation, 2010). Studies show that faulty and wrong decisions are often attributed to the stress experienced by drivers (Westerman and Heigney, 2000; Kontogiannis, 2006). Stress is a state of physical or psychological strain experienced by a person following an actual or perceived internal or external demand (Lazarus, 1966). In driving situations, stress could lead to an increased number of critical driving errors (Duncliffe et al., 2019). Few studies have hinted that novice drivers could be more susceptible to error-producing stress (Li et al., 2019, Nabatilan et al., 2011). However, current research is still lacking and is yet to provide conclusive evidence to prove the claim. Up until now, it remains as an indefinite assumption across the academia. Although there may be probable differences in susceptibility to stress between experienced and novice drivers, studies show that relationships between stress and expertise must be understood contextually (Matthews et al., 2019). Moreover, it was found that the negative effects of stress are found to be dependent not only on driver characteristics but to specific environments as well (Duncliffe et al., 2019; Hill and Boyle, 2007). Hence, this prompts for a context-specific examination of the relationship between stress and driving experience.

On the other hand, recognition error is often attributed to the failure to efficiently allocate one's attention. Numerous studies have proven that efficient attentional function is one of the requisite skills for safe driving (Trick et al., 2004). Similar to the susceptibility to stress while driving, overall attentional function is also found to be partly influenced by driving experience (Crundall and Underwood, 1998; Chapman and Crundall, 2010; Underwood et al., 2002). The general trend shows that expert drivers exhibits better attention allocation than novice drivers. However, results from the previous literature still shows inconsistent results regarding the relationship between attentional functions and driving experience during hazard situations. The lack of consensus may suggest that the connection between experience and attention could be context-specific. Thus, it is imperative to further investigate how the relative influence of experience in attention come to play during a specific hazard situation.

With all things considered, the goal of the present study is to bridge the gap in literature by investigating the differences between the stress-level and attentional functions of experienced and novice drivers during varying levels of intersection-related hazard situations. This study also aims to provide better objective-based evidences and scale up its contribution to the existing literature by utilizing multi-modal psychophysiological measurements in assessing stress-levels and attentional functions.

1.2 Research Objective

The main objective of this study is to determine the differences in stress-level and attentional functions between experienced and novice drivers during intersection-related hazard situations.

1.3 Organization of the Thesis

The thesis is composed of five chapters. The first chapter introduces the background and goal of this research. The second chapter provides a summary of the findings from previous studies related to the main theme of this thesis. The review contains research that tackles the probable effects of driving experience in overall driving performance, stress and attentional functions in the context of driving. The third chapter presents the details of the driving simulation experiment conducted in order to achieve the aim of this study. It includes a brief overview, statement of the hypotheses, methodology and results.The fourth chapter contains a discussion of the results of the experiment. Lastly, the last chapter includes the conclusion, limitation and suggestions for future direction.

Chapter 2

Literature Review

2.1 Overview

This chapter aims to provide a summary of the concepts, definitions and important findings from previous literature that relates to the scope of this research. Since the main goal of this study is to compare drivers with different levels of experience, research regarding driving experience and how it affects overall driving performance is discussed first. Followed by a review of the literature about stress and attentional functions in the context of driving. Moreover, the recent trends concerning the measurement of stress and attentional functions were also presented in this chapter.

2.2 Driving Experience and Performance

Driving is a common but very complex task. Although the basics of driving can be easily learned (Hall and West, 1996), a few days or weeks of experience might not be enough to acquire the necessary higher-order skills for safe driving. The absence of such skills or lack thereof can lead to various drawbacks such as casualties. Statistics on road crashes showed an overrepresentation of inexperienced drivers (Horswill and McKenna 2004). It was also found that novice drivers are almost ten times more prone to driving-related accidents than experienced drivers (NHTSA, 2002). The vulnerability of inexperienced drivers raises a myriad of concerns in ensuring traffic safety. Since driving experience appears to play a crucial role in safe driving, many researchers have come to investigate the underlying differences between novice and experienced drivers.

The lack of driving experience is often associated with inferior driving performance due to the absence of essential driving skills. In general, studies have shown that novice drivers exhibit poor vehicle control as opposed to experienced drivers. For example, in a study conducted by Lansdown (2002) it was found that during a driving simulation task, inexperienced drivers deviated out of the lane significantly more than expert drivers. On a similar note, in another simulation experiment, it showed that novice drivers' lane position variance during a lane change maneuver was also significantly higher than experienced drivers (Yang, Jaeger & Mourant, 2006). This may indicate that lane-keeping requires certain skills or amount of practice in order to be executed properly. In terms of speed control, unlike the expert drivers, young novice drivers tend to lose track of one's speed, which often results to over speeding (Braitman, Kirley, McCartt, & Chaudary, 2007). Moreover, research has shown that young novice drivers are more likely to lose control, run off the road and fail to yield the right way than experienced drivers (Williams, Ferguson, & Wells, 2005; Clarke, Ward, & Jones, 1998). These findings clearly show a clear gap between novice and experienced drivers in terms of driving performance. In most cases, inexperienced drivers' subpar performance is attributed to the dearth of psychomotor skills specific to driving.

Nevertheless, psychomotor skills required for vehicle control accounts only for a small portion of the differences between the two groups. In fact, on-road direction control and speed choice may be enhanced through short-term training (Isler et al., 2011). However, brief training is insufficient to improve higher-order skills such as hazard perception, which take on a bigger role in overall driving performance (Isler et al., 2011). Research have shown that differences in the underlying cognitive processes during the act of driving also accounts for the disparity between novice and expert drivers (i.e. Nabatilan et al., 2011).

For example, novice and experienced drivers appear to respond differently in mentally demanding and stress-inducing driving scenarios. In a study that investigated the effect of interference of a secondary task (i.e. using of a mobile phone), it was found that even though all of the subjects reported higher workloads and committed more errors when executing the secondary task, the errors were comparatively lower for experienced drivers (Nabatilan et al., 2011). Although different groups were given the same amount of task load, drivers with less driving experience appeared to handle the situation poorly. In addition, one finding revealed that across different stress-inducing scenarios, drivers with less experience displayed higher physiological fluctuations than drivers with more experience (Li et al., 2019). These results may be indicative of the vulnerability of novice drivers to experience higher levels of mental demand and stress during driving.

Moreover, an abundant source of research have explored the differences between experienced and novice drivers in terms of visual search strategies, hazard perception and attention allocation (i.e. Beanland and Wynne, 2019; Pemmer et al., 2018, Pradhan, Pollatsek, Knodle & Fisher, 2009). The general trend shows that there is a salient deficiency in the ability of inexperienced drivers to recognize hazard as much as experienced drivers do (Pradhan et al., 2009). In detecting hazards of different threat values, expert drivers are more likely to allocate their attention more efficiently than non-experts (Pemmer et al., 2018). Expert drivers exhibit heightened hazard awareness by detecting hazards of high and moderate threat value accurately while being efficient in disregarding non-threatening objects. Contrarily, non-experts fails to prioritize threat-related objects over non-threatening ones (Pemmer et al., 2018). In addition, an experiment that compared driving performance in different lighting conditions revealed a similar pattern wherein novice drivers scans for risk less than experienced drivers across all conditions (Garay et al., 2004). More specifically, it was found that novice drivers are scanning the risky areas less than 50 percent of the time during daytime conditions.

2.3 Stress

Stress is defined as a state of physical or psychological strain that results from the interaction between the demands of the environment and one's resources. It arises when a person perceives that one's available resources are not enough to meet the demands being placed on them (Lazarus, 1966). Feelings of stress are said to be individual-specific, that is, it heavily relies on the individuals' perception and assessment of the demands as well as the evaluation of one's capacity to meet those demands (LeBlanc, 2009).

Numerous studies from different fields have explored this phenomenon in various context and conditions. For example, studies in psychology show that an excessive amount of stress may have a negative impact on self-confidence, attention, working memory, perception and concentration (Goette et al., 2015; Arnsten, 2009; Lupien et al., 2007) Similarly, findings from linguistics studies confirm that stress can impede language processing and development (Perkins et al., 2013). On the other hand, research on physical education reveals that stress at an adequate level can help boost physical performance and concentration during sports competition but may be destructive if it becomes too high (Bali, 2015). Across the literature, the concept of stress has been interpreted and applied diversely.

In most studies, stress is linked to human performance. In many instances, stress was found to affect performance negatively (LeBlanc, 2009). However, some researchers also argue that stress is not at all negative and that it can help improve performance up to a certain extent (Nelson and Simmons, 2003). This contrasting view of stress has led to the distinction between eustress and distress (Selye, 1974). Eustress, known as the positive stress, is the perception that one is able to cope with the demands being placed on them, leading to an increased motivation to perform better in a given task. Whereas distress, the negative stress, occurs when a person thinks that the internal or external demands completely outweighs one's adaptive capacity (Seyle, 1974). This type of stress is the one that people often refer to when they talk about 'stress'. This is also the type of stress that will be discussed further in this review, as it is the type of stress that is detrimental during driving situations.

Moreover, stress can also be classified into three subclasses: acute, episodic and chronic. Acute stress occurs when a short-term or unexpected stressor emerges and causes the body to produce high levels of cortisol into the bloodstream that causes an individual to feel strain (Selye, 1956). This type of stress often last for a very short time from a few seconds to several hours and usually disappears when the stressor is gone. The other two types of stress are recurrent and continuous stresses that can cause severe adverse effects on one’s mental health.

2.3.1 Stress and Driving

Stress is often present during driving situations. Changes in the environment, road conditions, and the rise of unexpected situations place huge external demands on drivers which makes them feel stressed (Rodrigues et al., 2015). Drivers under stress can lead to a lot of consequences. Previous research has shown an association between stress and crash involvement. Stress has been identified as one of the main reasons for vehicle crashes (Katasis et al., 2015). Reports also show that stress is among the ten leading causes of fatal crashes in Australia (Beanland et al., 2013). The strong tie between stress and casualties have led many researchers to investigate the probable reason for this association.

Drivers experiencing stress on-road are more likely to be involved in dangerous situations because of overwhelming negative emotions (Ge et al., 2014) and increased tendency to commit critical driving errors (Duncliff et al., 2019). Moreover, perceived stress has been closely associated with aberrant driving behavior such as traffic violations and lapses (Kontogiannis, 2006). In a study that evaluated the driving performance of professional public transport drivers (bus, taxi and truck), it was found that stress is also one of the leading causes of maladaptive driving behavior (Machin & Hoare, 2008).

Further studies have confirmed the adverse effects of driver stress. For example, a group of researchers that studied the impact of stress in the driving abilities of paramedics claimed that heightened stress could lead to critical driving errors such as failure to wear a seatbelt, failing to stop for red lights or stop signs, and losing control of the vehicle (Duncliff et al., 2019). These detracting errors were attributed to the stress induced by alarming scenarios. This finding suggests that environmental pressure play a huge role in the manifestation of stress. In an evaluation of driver stress while transiting road tunnels, it was revealed that drivers experience elevated stress levels when they are uncomfortable with the situation. Also, it was suggested that in critical situations, the body might react with tonical immobility as part of stress response, which can cause harmful consequences on-road.

Furthermore, the impact of driving tasks and roadway conditions on driver's perceived stress were previously investigated through a survey. It was indicated that increase in stress while driving were influenced by age and gender, with female and older adults reporting higher levels of stress than male and younger drivers do. It was also revealed that stress depends not only on driver characteristics, but also on the specific driving environment. Thus, it was suggested that individual differences and driving context should be taken into account when investigating the effects of stress.

2.3.2 Driving Experience and Stress Susceptibility

Studies have suggested that the tendency to feel stress in driving situations could be driver-specific (Hill and Boyle, 2007). For example, across studies individual differences such as age, gender, driving experience and personality traits have shown influence over the susceptibility to driver stress (Mather et al., 2009; McLinton and Dollard, 2010; Oz et al, 2010). Among these factors, driving experience received the least amount of attention. Small pieces of evidence show that the lack of driving experience can lead to an increased susceptibility to error-producing stress (Li et al., 2019; Nabatilan et al., 2011). Drivers with low driving experience tend to respond negatively to stress induced by the driving situation (Manseer and Riener, 2014). Despite these plausible evidence, the relationship between driving experience and vulnerability to stress when driving remains to be understudied.

The discrepancy between experienced and novice drivers in terms of susceptibility to driving-induced stress may be attributed to the differences in mental workload. One of the factors that reduces mental workload in driving is task automation. Since task automation is progressively acquired through repeated actions and practice, novices may fail to exhibit task automation as much as experienced drivers (Patten et al., 2006). Thus, driving may induce higher mental workload for inexperienced drivers (Patten et al., 2006; Wickens and Hollands, 2000). This in turn could place more demands on novice drivers therefore, elevating one's stress levels. Moreover, this can be especially true during complex and hazardous situations where the distinction in mental workload is more evident (Paxion, Galy and Bethelon, 2014).

2.3.3 Psychophysiological Measures of Stress

Stress can be measured in a multitude of ways. Since stress is known to activate the sympathetic nervous system (SNS) of the body, stress responses are often measured through different biosignals. Biosignals often involve either biochemical or physiological measurements.

Two of the most commonly used biochemical marker for stress is adrenaline and cortisol (Wijsman, 2014). These biomarkers are often found in bodily fluids such as blood, saliva and urine. In a study that investigated the effects of stress on drivers, it was concluded that driving induced stress could be detected accurately through measuring the cortisol levels found in saliva (Yamaguchi et al., 2006). However, a recent finding has shown that cortisol levels are heavily influenced by other factors as well such as time of the day and wakefulness (Chennaoui et al., 2016). Thus, results from this measure should be interpreted with caution and must be applied only in well-controlled settings. On the other hand, adrenaline levels are known to be strongly linked to the fight-or-flight response induced by stress. However, only few experimental studies have utilized this method because of its obtrusiveness and impracticality. Since adrenaline levels can only be measured through intrusive methods such as blood sampling, it is often not recommended for most experimental research.

Aside from biochemical markers, psychophysiological measurements are widely used in stress research. In a comprehensive review of multimodal measurements of detecting driver stress, it was concluded that physiological signals are the most extensively used measures in the domain of driver stress detection (Rastgoo et al., 2018). Previously used psychophysiological measures for stress detection include heart rate activity, blood pressure, electrodermal activity, respiration response, muscle activation, skin temperature and pupillary response (Rastgoo et al., 2018). Among these measures, heart rate activity and electrodermal activity have established precision and reliability in detecting stress across the literature.

Using both supervised and unsupervised machine learning techniques, it was found that among six biosignals (electrocardiogram, electromyogram, hand galvanic skin resistance, foot galvanic skin resistance, heart rate, respiration) ECG performed the best in detecting stress, with an overall accuracy of 75.02% (Elgendi et al., 2020). Electrocardiogram (ECG) signals show the heart's electrical activity as it fluctuates within time (Price, 2010). ECG can present both heart rate (HR) and heart rate variability (HRV) features. HR refers to the number of heartbeat per minute whilst HRV refers to the variations in the heartbeat intervals or the instantaneous HR (Archaya et al., 2006). HRV reflects the activations in the sympathetic part of the autonomic nervous system (ANS) which is directly related to the feelings of stress. HRV time-domain measures such as the mean of R-to-R intervals (MRR), standard deviation R-to-R intervals (SDRR), mean normal-to-normal intervals (MNN), the standard deviation of normal-to-normal intervals (SDNN), square root of the mean squared difference of successive normal-to-normal intervals (RMSSD), and the number of pairs of successive normal-to-normal intervals that differ by more than 50ms (PNN50) have been utilized in several studies to measure instantaneous stress responses (Lee et al., 2007; as cited in Rastgoo et al., 2018). On the other hand, frequency-based measures such as high-frequency (HF), low-frequency (LF) and HF/LF ratio are used to measure stress and mental workload level (Healey and Picard, 2005). According to the literature, as the stress level increases HF values decrease while LF values increase.

On the other hand, electrodermal Activity (EDA), also known as skin conductance response (SCR) or galvanic skin response (GSR) is also found to be highly correlated with subjective stress experience. More specifically, it can distinguish different levels of stress across different stressful events (Paschalidis et al., 2019). It has been proven that the skin produces continuous variations in electrical activity in response to stress. Thus, high variations in EDA implies high levels of stress (Deng et al., 2013). Some of the most commonly extracted EDA features used for detecting driver stress include latency of first SCR, average phasic activity, variance of phasic signals, maximum phasic amplitude, amplitude-sum of SCRs, and phasic area under the curve (Lanata et al., 2015). Moreover, the summary of startle magnitudes, duration and the area of SCR orienting responses, sum of durations, sum of magnitudes, sum of estimated areas, and frequency of occurrence are also used as measures of stress levels (Healey and Picard, 2000).

In driving research, HRV is proven to be a reliable measure of psychophysiological stress during a realistic high-pressure driving situation (Brisinda et al., 2015). Moreover, in a study that collected various physiological data from 24 drives of at least 50-minutes in duration, it was confirmed that electrodermal activity and heart rate metrics were the best methods for determining driver's relative stress level (Healy and Picard, 2005). This was further affirmed by a recent study that stress experienced by drivers during a car-following task can be accurately detected through HR/HRV, blood pressure and skin conductance (Paschalidis et al., 2019).

2.3.4 Subjective Measures of Stress

Stress can also be measured through psychological evaluations and self-report stress questionnaires. Among the few, Stress Self Rating Scale (Alberdi et al., 2016), Stress Reaction Questionnaire (SASRQ) (Cardeña et al., 2000), Perceived Stress Questionnaire (PSQ) (Levenstein et al., 1993) are the psychometric tools that are often used to quantify perceived stress in various domains. In some studies, anxiety measurements such as Spielberger State-Trait Anxiety Inventory (STAI) are also used to measure stress since the operational definition of stress and anxiety sometimes overlaps. In driving research, subjective measurements such as Perceived Stress Scale (Cohen et al., 1983), the National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart and Staveland, 1988) and Driving Activity Load Index (DALI) (Pauzie, 2008) are commonly utilized. DALI is initially used to measure the driver's subjective evaluation of one's mental workload. It includes factors such as effort of attention, visual demand, auditory demand, temporal demand, interference, and situational stress (Pauzie, 2008). The last factor, which serves as the measure of driver stress, evaluates the level of constraints while driving (e.g. fatigue, insecure feeling, irritation, discouragement).

Subjective measures are useful tools in obtaining information about the driver's perceived level of stress. However, one weakness of this approach is that, since the drivers may have some trouble recalling acute stressful events, retrospective evaluation of acute stress may be unreliable to a certain extent. Thus, time controls and choice of the right tool should always be taken into account. Nevertheless, in most experimental studies, subjective measures are considered indispensable since it serves as a form of validation and is complementary to other objective measures.

2.4 Attentional Functions

Although the term 'attention' is widely used by many, an actual unified definition is yet to be determined. Attention is defined diversely across disciplines. For the most part, it refers to the allocation of cognitive resources to recognize and take in information in order to update one's knowledge and influence behavior (Mancas, 2016). However, attention is not just a single mechanism, but rather it involves multiple specific functions that interacts with other cognitive processes. This group of functions is called 'attentional functions'.

Attentional functions refer to the individual's ability to control their attention efficiently (Mackenzie and Harris, 2016). It describes one's level of vigilance to disrupting stimuli and the ability to sort out information effectively. Attention functions involve three distinct yet interconnected cognitive networks namely: executive function, alerting and orienting aspects (Posner and Petersen, 1990). Executive function refers to the ability to resolve conflicts by choosing the most relevant information in a plethora of available stimuli. Alerting aspect involves being able to maintain a state of readiness to respond for an incoming stimulus. While orienting aspect refers to the ability to shift one's point of thought or concentration towards the location of a stimulus.

Attentional functions are essential to accomplish daily tasks. It plays a huge role in other cognitive processes such as perception, memory, behavioral planning and actions, to name a few (Leclercq and Zimmermann, 2004). These functions are especially important during hazardous and threatening situations. In a study, it was revealed that under increasing levels of uncertainty, low efficiency in attentional functions results in decreased efficiency in cognitive control (Mackie et al., 2013). Thus, efficiency in attentional functions must be maintained particularly in situations that requires optimum cognitive control and performance.

2.4.1 Attention and Driving

Driving is considered to be a complex activity that requires a wide range of cognitive and psychomotor skills in order to be performed competently. It is also regarded as a mentally demanding task where attention must be consistently deployed to vehicle control, visual displays within the vehicle and the external driving scene. Thus, it is inarguable that one of the requisite skills for safe driving is having efficient attentional functions (Trick et al., 2004). Attention in driving is often studied in conjunction with crash involvement and tendencies. For example, previous reports have shown that the majority of traffic accidents are attributed to driver error, particularly lapses in attention (Olson et al., 2009; Klauer et al., 2006). Similarly, inattention and subsequent failures to scan the roadway are often regarded as one of the major contributing factors to road accidents (Dingus et al., 2006; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Lee, 2008).

Among the five categories of "human functional failures" that leads to road accidents as identified by Van Eslande and Fouquet (2007), the first failure, which is information acquisition, may be attributable to poor attentional functions. In essence, failure to take in information from the environment signifies inattention or inefficient utilization of one's attentional functions. The other categories (i.e. failures in diagnosing the situation, failures in predicting the situation, failures in deciding to make a particular maneuver, failures in performing an action, and failures relating to driver state) that were identified are also closely tied with attention as well. These failures can be seen as subsequent consequences resulted from the inability to control one's attention efficiently.

There has been a lot of studies and theories on how attentional functions affects driver performance, especially in hazardous and complex environment. In a study that tested older drivers through different psychological, physical and standardized on-road driving tests, it was found that the best predictor of on-road driving performance is visual attention (Baldock et al., 2007). In intersection-related accidents, failure to correctly recognize or assess hazards is identified to be one of the biggest contributing factors for these mishaps (US Department of Transportation, 2010). In general, attention is a major component for hazard perception. The ability to recognize and assess hazards requires efficient attentional functions. A driver must effectively allocate one's visual attention to relevant stimuli and filter out irrelevant information.

In human factors research, one of the models which attempted to explain the underlying processes in attention is the SEEV (Saliency, Effort, Expectancy, Value) model developed by Wickens and colleagues (2001). The model was originally established to understand visual attention allocation in aviation context. However, it has been applied in various other domains including driving. The SEEV model proposes that visual attention allocation is affected by both top-down and bottom-up components. Top-down components includes expectancy and value while bottom-up approaches refers to salience and effort (Wickens et al., 2001). This model posits that attention allocation is influenced by both internal and external factors. Internal factors may include prior knowledge, experience, personality tendencies, and internal states. While external factors may include environment complexity among many others.

2.4.2 Driving Expertise and Attention

Although it is known that inexperienced drivers are more at risk for road accidents than experienced drivers, what is not commonly discussed is the fact that the causes of the accidents also differ as a function of driving experience. In a study that analyzed 1,396 police reports of accidents in California, it was revealed that accidents caused by inattention was far more common in young novice drivers than older experienced drivers (Lestina and Miller, 1994). Further investigation also showed that inexperienced drivers are more likely to be involved in distraction-related accidents than more experienced drivers (Stutts et al., 2001). For novice drivers, failure to search the road way was revealed to be the single most frequent cause of road accidents (Lestina and Miller, 1994).

Many studies have showed that novice drivers generally exhibits weaker attentional functions than experienced drivers do, most especially in hazard situations. Previous findings showed that inexperienced drivers tend to detect fewer hazards than experienced drivers (McKenna & Crick, 1991; Summala, 1987). Evidence from a driving simulation experiment showed that only 38.2% of novice drivers, in contrast with 73.6% of the experienced drivers, recognized the potential risk in a given driving scenario (Garay-Vega & Fisher, 2005). Similar findings also showed that novice drivers are less likely to notice potential threats (e.g. a pedestrian crossing the road unexpectedly) than more experienced drivers (Sagberg & Bjormsaku, 2006). Moreover, research has shown that novice drivers are also slower in terms of recognizing potential risks (McKenna & Crick, 1991). In one study, novice drivers took an average of 0.25 second longer than experienced drivers to detect peripheral targets (Patten, Kircher, Ostlund, Nilsson & Svenson, 2006). Altogether, these findings could suggest that hazard detection and visual scanning patterns while driving can differ as a function of experience.

In many studies, differences in attention functions between novices and experts are investigated through analyzing the eye-movements such as gaze and fixations. For example, Borowsky, Shinar and Oron-Gilad (2007) tried to compare the eye-movements of young-inexperienced drivers, experienced drivers, and elderly-experienced drivers while observing six hazard perception movies. In the study, the participants were asked to press a button upon the recognition of a hazard. The results showed that all of the subject groups recognized salient hazards, however, gazing towards the side at T-intersections were only evident for experienced drivers while inexperienced drivers tend to just gaze ahead of the road (Borowsky, Shinar & Oron-Gilad 2007). A similar finding also showed that by showing video clips of potential hazards both younger and older drivers exhibited sensitivity to attention capture by the appearance of an incoming hazard as evidenced by their eye fixations and scanpaths (Underwood et al., 2005). However, the aforementioned studies only investigated eye-movements through showing video clips of a driving scenario. This in turn may not be a good representative of how eye-movements differ as a function of experience since there is no actual driving task involved. Thus, in order to get a better view on the differences in attentional functions, the inclusion of an actual driving task is deemed necessary.

To expand the previous knowledge about attentional functions, some studies utilized driving simulators to test actual differences in attention based on eye tracking metrics. For example, one study tested drivers with different levels of experience on their approach to a series of on-road hazards through a driving simulator (Crundall et al., 2012). Results of the experiment showed that learner drivers took longer to fixate to hazards and were more likely to miss hazards that were obscured by the environment. On the contrary, drivers with moderate to high amount of experience were quick to fixate to hazards. These differences in the sequences of fixations were also found in another study that investigated the drivers' attention distribution in different road types (Underwood et al., 2003). It was concluded that novice and inexperienced drivers exhibited different fixation patterns and that experienced drivers showed greater sensitivity across different road conditions. In terms of fixation patterns, some studies suggests that experienced drivers have a higher tendency to exhibit a wider horizontal search, which is visually scanning from left to right, than inexperienced drivers (Crundall and Underwood, 1998; Chapman and Crundall, 2010; Underwood et al., 2002). Given these points, it strongly suggests that attentional functions of drivers may differ as a function of experience.

2.4.3 Eye-tracking Measures of Attention

Attention, being a broad range of different functions, has been studied using various types of measures. Among the many, eye-tracking metrics have proven its reliability and validity as an objective and explicit measure of attentional functions across studies in various domains.

Eye- tracking metrics has been widely used for measuring and understanding both cognitive and affective mechanisms. In a summary provided by Rahal and Fiedler (2019) regarding how different eye-tracking measures is used and interpreted in the field of social psychology, it can be inferred that such measures are highly functional and multifaceted. For example, metrics such as fixation duration and dwell time within an AOI are considered to represent the cognitive processing of depth and effort. Whereas fixation counts and inspected information is able to measure a person's search and processing extent. Proportion of attention, which is the fixation count directed towards a specific AOI relative to the overall fixation count in a given trial, and first and last fixations accounts for the cognitive process of weighting information. Lastly, metrics such as transitions and scan paths are usually used to investigate search and decision strategies (Rahal and Fiedler, 2019).

2.4.4 Subjective Measures of Attention

Attention, being a broad concept, is often measured objectively through physiological tests or through performance tasks. Subjective measures of attention often involve self-report questionnaires about the perceived attentional load in a given task. For example, the Divided Attention Questionnaire (DAQ) is used to measure the level of difficulty and attention load during dividing attention tasks (Tun and Wingfield, 1995). On a different note, a more popular subjective measure for attention would be NASA-TLX (Task Load Index) developed by Hart and Staveland (1988). NASA-TLX is a multi-dimensional rating scale that aims to measure the magnitude and sources of six workload-related factors. Although it is originally used to measure workload, many studies have considered using it as a supplementary tool to measure attentional load. For attention measures specific to driving tasks, the Driving Activity Load Index (DALI) developed by Pauzie (2008) is often utilized. One of the main facets of DALI includes general attention load.

Chapter 3

Driving Simulation Experiment

3.1 Overview and Hypotheses

A review of the literature showed disparities between novice and experienced drivers in terms of accident-proneness, driving performance and higher-order cognitive skills that are necessary for driving. However, the underlying cause of such differences remains to be equivocal. Previous findings showed that stress-levels and attentional functions greatly contributes to driving performance and safety. Thus, this driving simulation experiment aims to investigate the differences in the stress levels and attentional functions between novice and experienced drivers. Considering the results from previous studies, the present study proposes the following hypotheses:

1.) Novice drivers will experience higher levels of stress than experienced drivers with increased level of hazard while driving.
2.) Novice drivers will exhibit less efficient attentional functions than experienced drivers with increased level of hazard while driving.

3.2 Methods

3.2.1 Participants

A total sample of 21 licensed drivers, 15 males and 6 females, were recruited to participate in a driving simulation experiment. The average age of the participants is approximately 27 years (min = 23, max = 33) and the corresponding standard deviation is 3.62. The participants were divided into two groups, experienced and novice group, based on the length of driving experience and frequency of driving per month. A simple test of difference showed that experienced and novice groups are significantly different in terms of age ($p = 0.017$), driving experience ($p = 0.004$) and driving frequency ($p = 0.011$). Novice drivers are generally younger with mean age 25.78 than experienced drivers with mean age of 29.86. Novice group has an average driving experience of 2.69 years while the experienced group have 8.77 years. Experienced drivers drive more frequently at an average rating of 2.89, which corresponds to approximately 15 to 21 times a month, while novice drivers drive at about less than 7 times a month. In addition, experienced drivers reported being involved in road accidents slightly higher than novices did. Table 1 shows descriptive statistics for the groups based on the collected demographics and driving history.

All participants were asked to not to smoke, drink alcohol and caffeine, or do heavy exercise one day prior the scheduled experiment. In addition, none of the participants reported any pre-session fatigue.

Table 1: *Participant Descriptive Statistics*

	Novice Drivers	Experienced Drivers	Significance t-test
Age in years	25.78	29.86	0.017
Driving experience in years	2.69	8.77	0.004
Driving frequency in days per month	1.00	2.89	0.011
Number of driving-related accidents since obtaining a license	1.33	1.86	0.26

3.2.2 Apparatus

Driving Simulator

The experiment was conducted using the UC-win/Road driving simulator (Forum 8 Inc., Japan). The simulator is made up of a car seat, steering wheel, accelerator and brake pedals. The visual display system includes three LED monitors, which spans a 180-degree field of view for a more realistic viewing experience. UC-win/Road software program is originally used for interactive visual reality (VR) modelling for urban planning, traffic modelling etc. Previous study have confirmed the validity UC-win/Road driving simulator in replicating a variety of road safety outcomes and in evaluating driving performance (Meuleners and Fraser, 2015).

Electrocardiogram (ECG) and Electrodermal Response (EDA)

Physiological data were collected using the BIOPAC MP160 ECG and EDA modules with a sampling rate of 2000 Hz (BIOPAC Systems Inc., USA). For ECG, disposable electrodes were attached in a three-lead chest-mounted configuration with one electrode under each clavicle and one on the lower left rib. On the other hand, to measure skin conductance, two BIOPAC LEAD11A electrodes were attached to the index and middle finger of the non-dominant hand of the participant.

Eye-Tracking Device

Eye movements were measured using Tobii Pro Glasses 2 (Tobii Pro, 2017). This device works by recording point-of-gaze onto a video image of the binocular corneal reflection with respect to the cameras mounted on the glasses. The glasses is equipped with five cameras. Four cameras facing the eyes are used to capture the relative position of the pupil and corneal reflection while a wide-angle HD scene camera is used to record what the subject sees.

Figure 1. Experimental set-up and apparatus. (A) Electrodermal Response EDA (B) Electrocardiogram ECG (C) Tobii Pro Glasses 2 Eye-Tracking Device

3.2.3 Measures

Driving Performance

Since the basic task for this experiment includes driving at the same lane for a constant speed, in this experiment, driving performance was measured based on speed deviation and lane deviation.

Stress Levels

Stress levels were measured through both psychophysiological and subjective measures. Psychophysiological measures included cardiac activity and electrodermal activity. For cardiac activity, ECG time-domain features that were extracted were mean of R-to-R intervals (MRR), standard deviation R-to-R intervals (SDRR) and mean squared difference of successive normal-to-normal intervals (RMSSD). Meanwhile, the ECG frequency-based features that were extracted were high-frequency (HF), low-frequency (LF) and HF/LF ratio. For electrodermal activity, the features that were extracted to measure stress levels were skin conductance response (SCR), amplitude-sum of SCRs and maximum phasic amplitude. These features are closely tied to changes in stress level according to various literature. On the other hand, the Driving Activity Load Index (DALI) Situational Stress factor was used to measure the subjective stress perception of the subjects.

Attentional Functions

Attentional functions was objectively measured through AOI-based and non-AOI based eye-tracking metrics. AOI-based measures included fixation count, average fixation duration and time-to-first-fixation. The AOIs that were considered in this experiment are front view, side monitors, and speedometer (see Fig. 2). Additionally, horizontal spread of search were extracted as a non-AOI based measure. For the subjective measure of attention load, the Driving Activity Load Index (DALI) General Attention Load factor was utilized.

Figure 2. Areas of Interest (AOI)

3.2.4 Experimental Design

The experiment consisted of nine trials with three levels of hazard conditions (no hazard, low hazard, high hazard). The hazard conditions were randomized across the nine trials for counterbalancing. Every trial requires driving in a 3km-long highway and passing by three 4-way intersections at a maintained speed of 80km per hour (see Fig. 3). The distance between each intersection is about 750 meters.

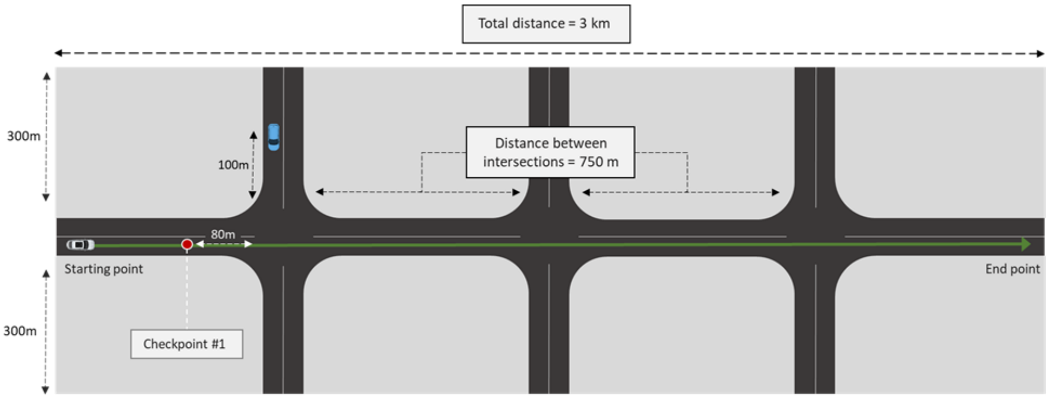

Figure 3. Driving route per trial

For each trial, the hazard scenario appears at one of the intersections at random to eliminate the learning and expectancy bias. The three hazard conditions include the following:

1. **No hazard.** In this condition, the participants drove pass by the three intersections without any event occurring (see Fig. 4a). Also, there was no other moving vehicle in this scene.

2. **Low hazard.** At one of the intersections, a blue SUV drives at 80km/hr from the left or right side of the intersection towards the same direction as the participant (see Fig. 4b, 4d).

3. **High hazard.** At one of the intersections, a blue SUV drives at 90km/hr from the left or right side of the intersection to the opposite side, crossing the participant's route (see Fig. 4c, 4e).

For low and high hazard scenarios, the blue SUV appears on the visual scene when the participant drove pass the checkpoint 80 meters before arriving at the intersection. At the checkpoint, the incoming vehicle appears on the participant's visual field. This is the basis for the start of the hazard event, hence the basis for determining the time-of-interest in analyzing both eye-tracker and galvanic skin response measurements.

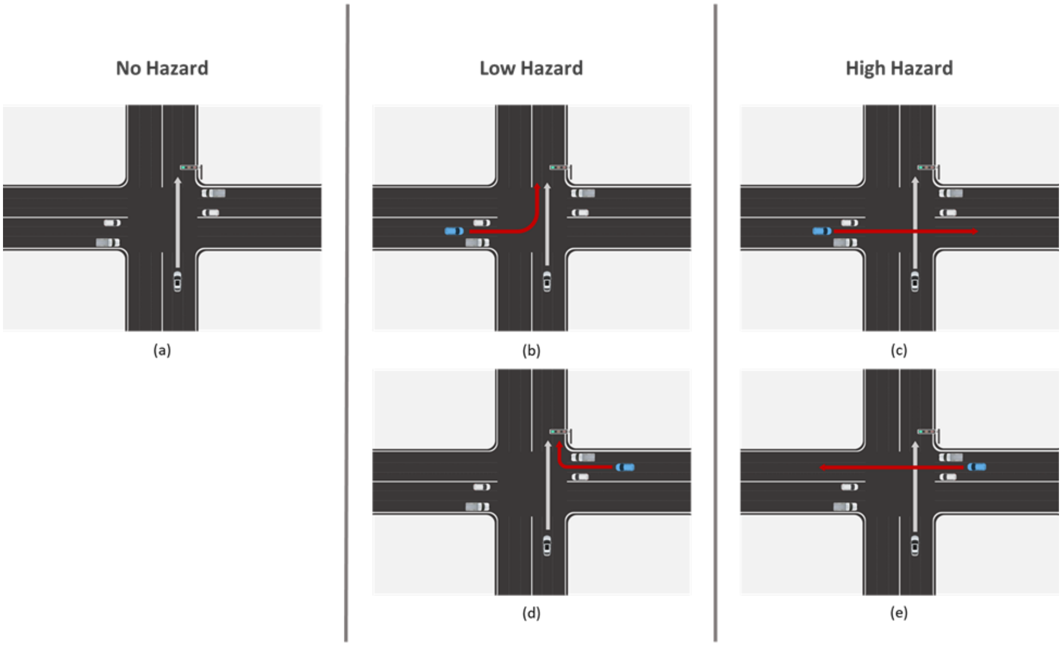

Figure 4. Driving conditions: (a) no hazard (b),(d) low hazard (c),(e) high hazard

3.2.5 Experimental Procedure

Participants were briefed about the procedures that will be undertaken for the study. All the sensors and devices that will be used were shown and the participants were informed about the collection of the physiological data throughout the experiment. After the short briefing, all of the participants provided informed consent and agreed to participate in the conditions set by the researchers.

Upon the consent of the participants, the researchers attached the sensors (ECG and EDA) to them. Baseline data were collected for both ECG and EDA while the participants were sitting at rest for two minutes. After the baseline data collection, they were fitted with the eye-tracker. The eye tracker was then calibrated by asking the participant to look at the calibration card for a few seconds. Accuracy of the calibration was checked by asking the participants to look at various areas pointed out by the researcher. Recording of the eye-tracking data started right after ensuring its accuracy.

Participants were asked to sit in the driving simulator and was presented with instructions regarding the tasks they have to accomplish. They were told that there are three main goals that they have to keep in mind during the experiment. First, they must maintain their speed at 80 km/hr. Second, they must stay on the second lane throughout the whole trial. Lastly, they must drive safely and avoid any possible collisions. Before the actual experimental trial, the seat were adjusted based on the subject's preference and drove for about a minute or two as a test drive. Participants were allowed to test drive a couple of times until they get comfortable to the simulator set-up.

The main experiment took place after the test drive. The task involved a completion of three blocks of nine randomized trials. Each trial lasted for approximately three minutes. After every trial, GSR was calibrated and the participants were asked to complete the subjective questionnaire.

In the end, the participants were asked about their experience and were debriefed.

3.2.6 Data Analysis

All of the dependent variables (driving performance, stress-levels and attentional functions) in this study were analyzed through a two-way mixed analysis of variance

(ANOVA) at a significance level of 0.05. The results of the ANOVA were further analyzed and modified by conducting Greenhousse-Geisser adjustments when Mauchly's test of sphericity was violated. Post-hoc analysis was also conducted through conducting multiple pairwise comparisons and Bonferroni correction to investigate the main effects. All statistical analyses were conducted using the statistics program R (ver. 3.6.1).

3.3 Results

The results of the analyses are presented in sequence based on the research questions of this study. The results of driving performance is presented first, followed by stress levels and attentional functions. Descriptive statistics, two-way mixed analysis of variance and post-hoc pairwise comparisons with Bonferroni corrections for driving performance, stress-levels and attentional functions are illustrated and summarized through tables and figures.

3.3.1 Driving Performance

The mean and standard deviations of the variables for driving performance per group and condition are presented in Table 2. From the table it can be seen that generally, the experienced group had lesser mean speed deviation (no hazard = 0.71($\pm$0.64), low hazard = 2.07($\pm$2.47), high hazard = 2.01($\pm$3.37)) and mean lane deviation (no hazard = 0.19($\pm$0.14), low hazard = 0.31($\pm$0.16), high hazard = 0.29($\pm$0.20)) than the novice group (speed deviation: no hazard = 1.36 ($\pm$1.51), low hazard = 2.21($\pm$1.95), high hazard = 2.07($\pm$1.60)), (lane deviation: no hazard = 0.22($\pm$0.18), low hazard = 0.40($\pm$0.27), high hazard = 0.41($\pm$0.25)).

Table 2. *Descriptive Statistics for Driving Performance*

Group	Condition	Mean (SD)	
		Speed Deviation	Lane Deviation
Novice	No Hazard	1.36 (±1.51)	0.22(±0.18)
	Low Hazard	2.21(±1.95)	0.40(±0.27)
	High Hazard	2.07(±1.60)	0.41(±0.25)
Experienced	No Hazard	0.71(±0.64)	0.19(±0.14)
	Low Hazard	2.07(±2.47)	0.31(±0.16)
	High Hazard	2.01(±3.37)	0.29(±0.20)

The results of the Two-Way Mixed ANOVA for driving performance is summarized in Table X. Results showed that hazard conditions had a significant main effect on both speed deviation ($F(1,38) = 16.44$, $p < 0.001$) and lane deviation ($F(1,38) = 16.45$, $p < 0.001$). However, experience had no significant main effect on speed deviation ($F(1,19) = 1.189$, $p = 0.289$) and lane deviation ($F(1,19) = 3.089$, $p = 0.094$) across the two groups. Also, there were no interactions between experience and condition in terms of speed deviation ($F(1,38) = 0.620$, $p = 0.794$) and lane deviation ($F(1,38) = 16.45$, $p = 0.163$).

Table 3. *ANOVA Summary Table for Driving Performance*

	Speed Deviation	**Lane Deviation**
Experience	$F(1,19) = 1.189$	$F(1,19) = 3.089$
Condition	$F(1,38) = 16.44$***	$F(1,38) = 16.45$***
E×C	$F(1,38) = 0.620$	$F(1,38) = 1.903$

* $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Results of the post-hoc analysis with Bonferroni correction revealed that the speed deviation and lane deviation were significantly lower in no hazard condition than were those in both the low hazard condition ($p < 0.01$, $p < 0.01$) and high hazard condition ($p < 0.01$, $p < 0.01$). However, low hazard and high hazard conditions did not show any significant differences ($p = 0.09$) (see Figure 5 and 6).

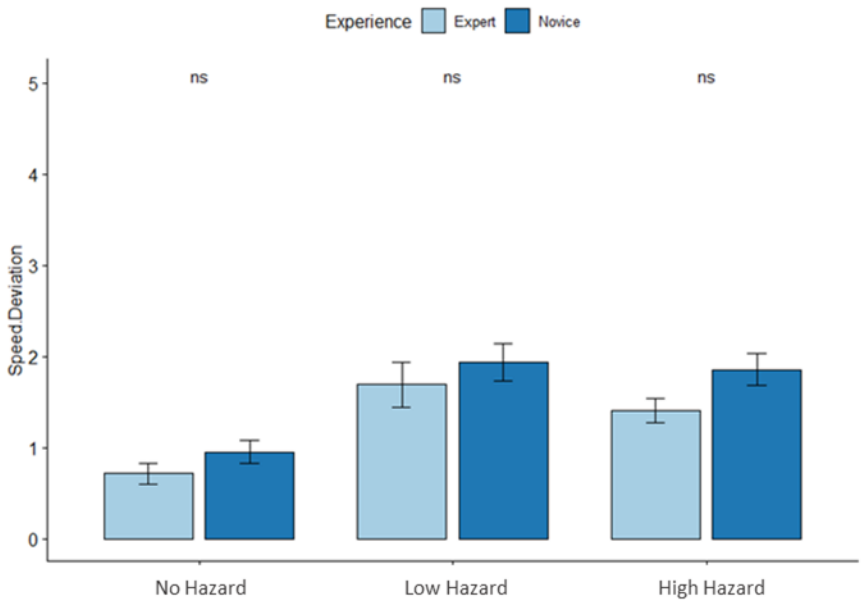

Figure 5. Speed Deviation

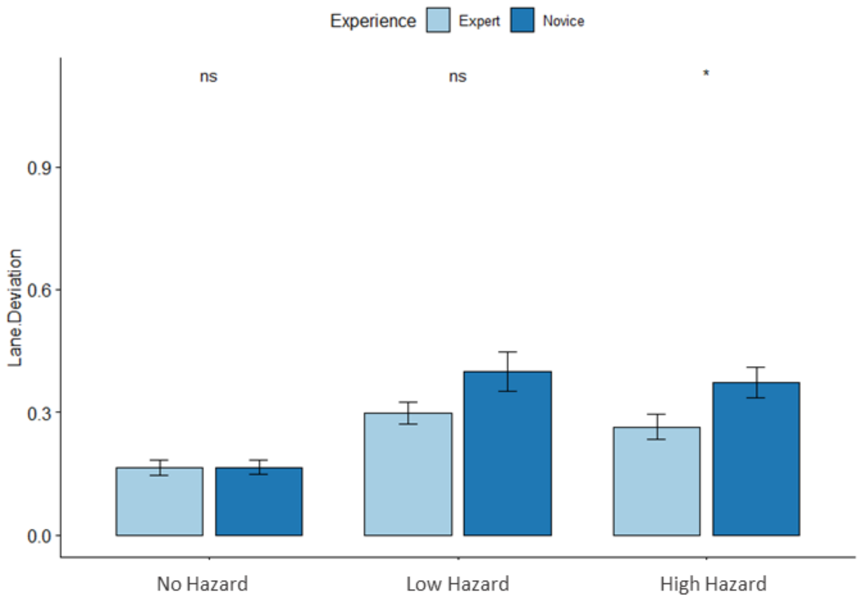

Figure 6. Lane Deviation

3.3.2 Stress Levels

The results for the measures of stress levels are mainly divided into three parts: electrocardiogram (ECG) signals, electrodermal response (EDA) signals and subjective measures.

Electrocardiogram (ECG)

The mean and standard deviations of the variables for electrocardiogram signals per group and condition are presented in Table 4.

Table 4. *Descriptive Statistics for Electrocardiogram (ECG)*

Group	Condition	Mean (SD)					
		Time Domain (ms)			Frequency Domain (Hz)		
		MRR	SDRR	RMSSD	HF	LF	HF/LF
Novice	No Hazard	1.03 (±0.05)	1.07 (±0.36)	1.15 (±0.42)	1.34 (±1.06)	1.55 (±1.26)	1.45 (±1.30)
	Low Hazard	1.04 (±0.05)	1.07 (±0.43)	1.07 (±0.36)	1.19 (±0.78)	1.77 (±1.74)	1.77 (±2.14)
	High Hazard	1.04 (±0.05)	1.14 (±0.42)	1.12 (±0.28)	1.16 (±0.68)	2.03 (±2.13)	2.13 (±2.78)
Experienced	No Hazard	1.01 (±0.06)	0.794 (±0.29)	0.809 (±0.25)	0.662 (±0.44)	1.15 (±1.13)	2.28 (±2.26)
	Low Hazard	1.02 (±0.06)	0.818 (±0.32)	0.815 (±0.26)	0.600 (±0.30)	1.32 (±1.72)	2.48 (±2.64)
	High Hazard	1.02 (±0.05)	0.805 (±0.28)	0.805 (±0.24)	0.600 (±0.35)	1.20 (±1.36)	2.26 (±1.98)

Note: mean of R-to-R intervals (MRR); standard deviation of R-to-R intervals; mean squared difference of successive normal-to-normal intervals (RMSSD); high-frequency (HF); low-frequency (LF); high frequency and low frequency ratio (HF/LF)

The results of the Two-Way Mixed ANOVA showed that experience had a significant main effect on standard deviation of R-to-R Intervals (SDRR) ($F($1,17) = 6.734, p = 0.018), mean squared difference of successive normal-to-normal intervals (RMSSD) ($F($1,18) =6.092*, p = 0.023) and high-frequency (HF) ($F($1,18) = 5.273, p = 0.033). However, it did not show any main effect on mean of R-to-R intervals (MRR) ($F($1,18) = 0.454, p = 0.509), low-frequency (LF) ($F($1,17) = 3.329, p = 0.085), and high-frequency and low-frequency ratio (HF/LF) ($F($1,17) =2.780, p = 0.113). On the other hand, results also showed that condition did not have any main effects on MRR ($F($1,36) = 1.169, p = 0.322), SDRR ($F($1,34) = 0.455, p = 0.638), RMSSD ($F($1,36) = 0.250, p = 0.779), HF ($F($1,18) = 0.274, p = 0.761), L$F(F($1,34) = 0.040, p = 0.960), HF/LF ($F($1,34) = 1.565, p = 0.223). Lastly, there were also no significant interactions between experience and condition in terms of MRR ($F($1,36) = 0.685, p = 0.510), SDRR ($F($1,34) = 0.091, p = 0.913), RMSSD ($F($1,36) = 0.565, p = 0.573), HF ($F($1,36) =0.308, p = 0.736), L$F(F($1,34) =0.856, p = 0.433), HF/LF ($F($1,34) =0.633, p = 0.537).

Table 5. *ANOVA Summary Table for Stress Levels: Electrocardiogram (ECG)*

	Time Domain			Frequency Domain		
	MRR	SDRR	RMSSD	HF	LF	HF/LF
Experience (E)	$F(1,18)$ =0.454	$F(1,17)$ =6.734*	$F(1,18)$ =6.092*	$F(1,18)$ =5.273*	$F(1,17)$ =3.329	$F(1,17)$ =2.780
Condition (C)	$F(1,36)$ =1.169	$F(1,34)$ =0.455	$F(1,36)$ =0.250	$F(1,18)$ =0.274	$F(1,34)$ =0.040	$F(1,34)$ =1.565
E × C	$F(1,36)$ =0.685	$F(1,34)$ =0.091	$F(1,36)$ =0.565	$F(1,36)$ =0.308	$F(1,34)$ =0.856	$F(1,34)$ =0.633

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Note: mean of R-to-R intervals (MRR); standard deviation of R-to-R intervals; mean squared difference of successive normal-to-normal intervals (RMSSD); high-frequency (HF); low-frequency (LF); high frequency and low frequency ratio (HF/LF)

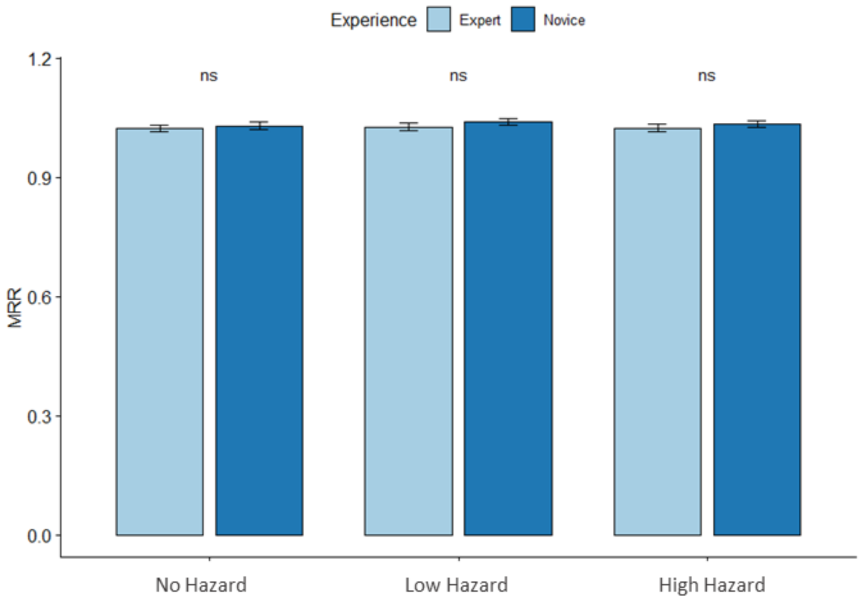

Figure 7. Mean of R-to-R Intervals (MRR)

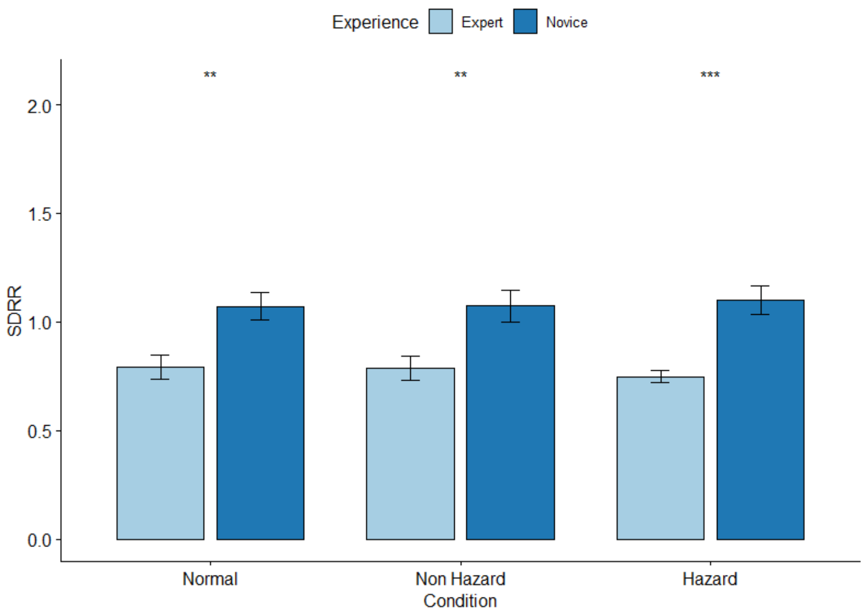

Figure 8. Standard Deviation of R-to-R Intervals (SDRR)

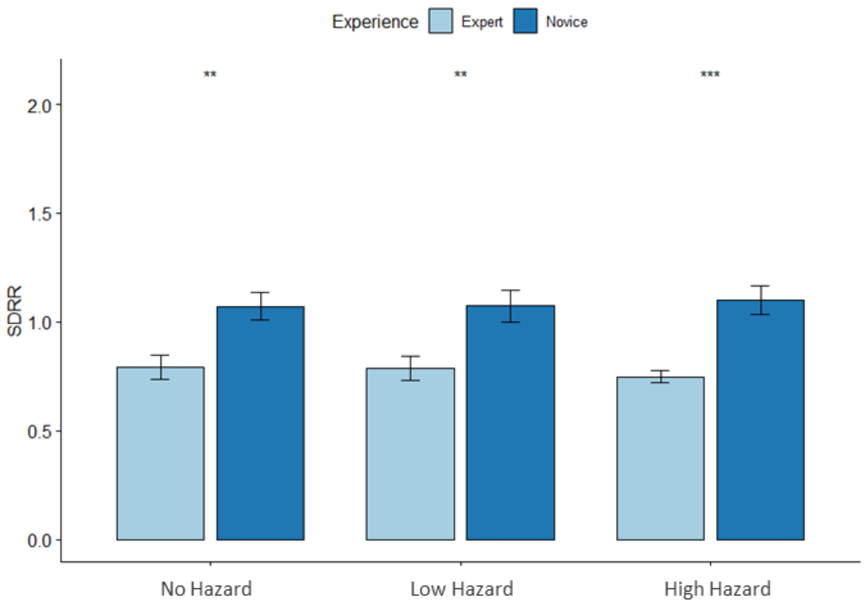

Figure 9. Mean Squared Difference of Successive Normal-to-Normal Intervals (RMSSD)

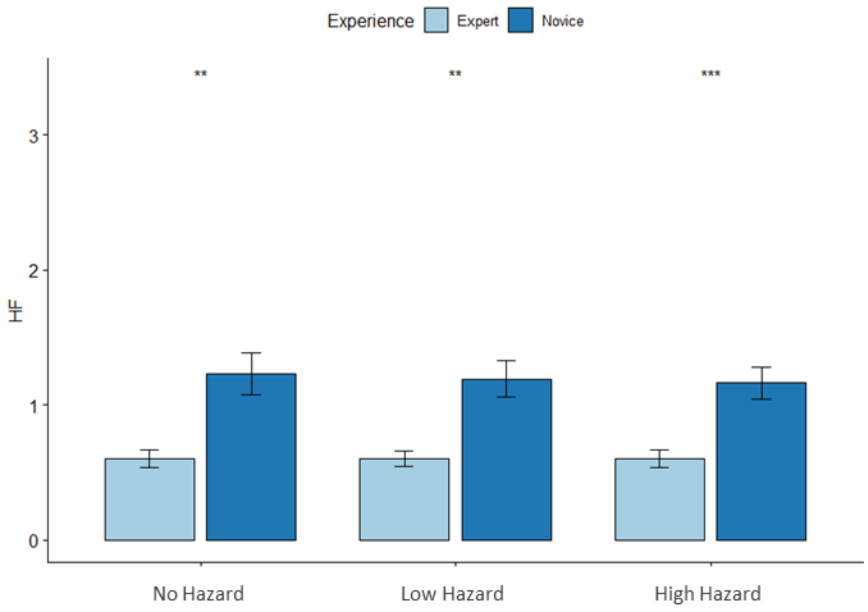

Figure 10. High-Frequency (HF)

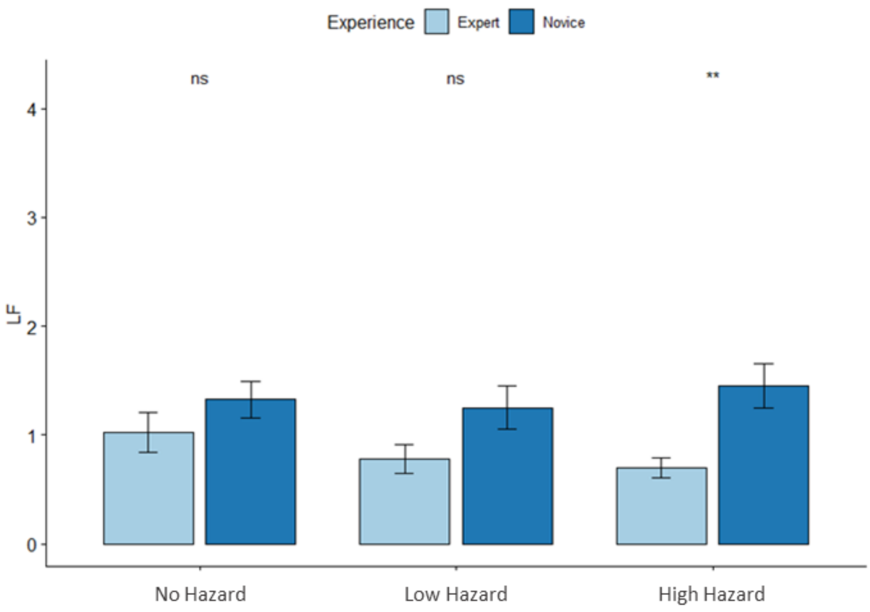

Figure 11. Low-Frequency (LF)

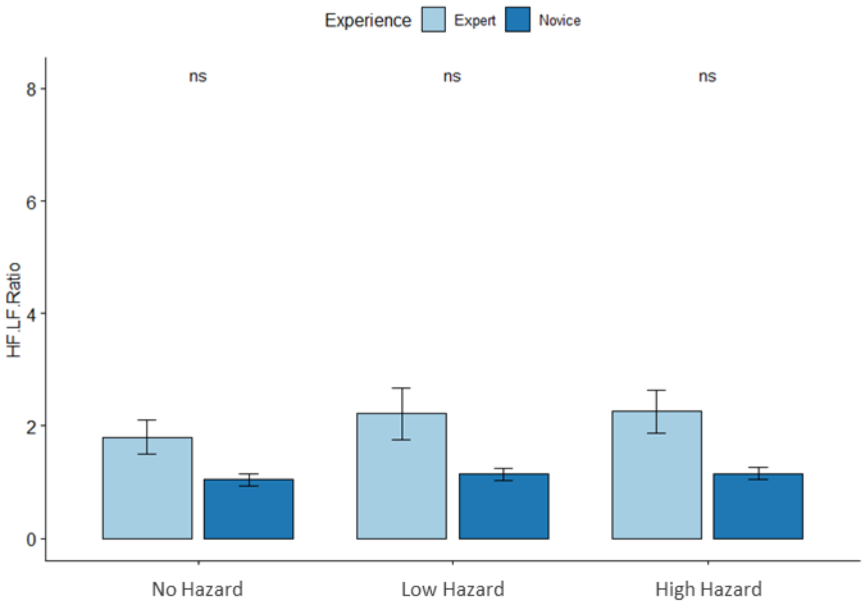

Figure 12. High-frequency and Low-frequency Ratio (HF/LF)

Electrodermal response (EDA)

The mean and standard deviations of the variables for electrodermal response signals per group and condition are presented in Table 6.

Table 6. *Descriptive Statistics for Electrodermal response (EDA)*

Group	Condition	Mean (SD)		
		Skin Conductance Response (SCR)	Amplitude Sum of SCR (μmho)	Maximum Phasic Amplitude (μmho)
Novice	No Hazard	0.427 (±1.63)	0.807 (±3.67)	1.22 (±3.89)
	Low Hazard	1.13 (±2.28)	1.05 (±2.38)	1.95 (±3.46)
	High Hazard	1.14 (±1.53)	1.20 (±2.20)	2.13 (±2.71)
Experienced	No Hazard	0.105 (±0.162)	0.122 (±0.292)	0.319 (±0.379)
	Low Hazard	0.365 (±0.536)	0.233 (±0.442)	1.02 (±1.28)
	High Hazard	1.01 (±1.40)	1.11 (±1.63)	1.93 (±2.23)

The results of the Two-Way Mixed ANOVA revealed that experience did not have any significant main effect on skin conductance response (SCR) ($F(1,18) = 0.785$, $p = 0.387$), amplitude sum of SCR ($F(1,19) = 0.137$, $p = 0.715$), and maximum phasic amplitude ($F(1,18) = 0.191$, $p = 0.666$). In contrast, the main effect of condition was evident in SCR ($F(1,36) = 12.04$, $p < 0.001$) amplitude sum of SCR ($F(1,38) = 14.91$, $p < 0.001$) and maximum phasic amplitude ($F(1,36) = 15.29$, $p < 0.001$). On the other hand, there were no significant interactions between experience and condition on SCR ($F(1,36) = 0.942$, $p = 0.399$), amplitude sum of SCR ($F(1,38) = 0.250$, $p = 0.779$) and maximum phasic amplitude ($F(1,36) = 0.137$, $p = 0.875$) .

Table 7. *ANOVA Summary Table for Stress Levels: Electrodermal response (EDA)*

	Skin Conductance Response (SCR)	Amplitude Sum of SCR	Maximum Phasic Amplitude
Experience (E)	$F(1,18) = 0.785$	$F(1,19) = 0.137$	$F(1,18) = 0.191$
Condition (C)	$F(1,36) = 12.04$ ***	$F(1,38) = 14.91$ ***	$F(1,36) = 15.29$***
E × C	$F(1,36) = 0.942$	$F(1,38) = 0.250$	$F(1,36) = 0.137$

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Results of the post-hoc analysis with Bonferroni correction indicated that the skin conductance response, amplitude sum of SCR and maximum phasic amplitude in the high hazard condition is significantly higher than both the low hazard and no hazard condition. However, low hazard and no hazard condition did not show any significant differences across all variables ($p = 0.1$, $p = 0.2$, $p = 0.06$).

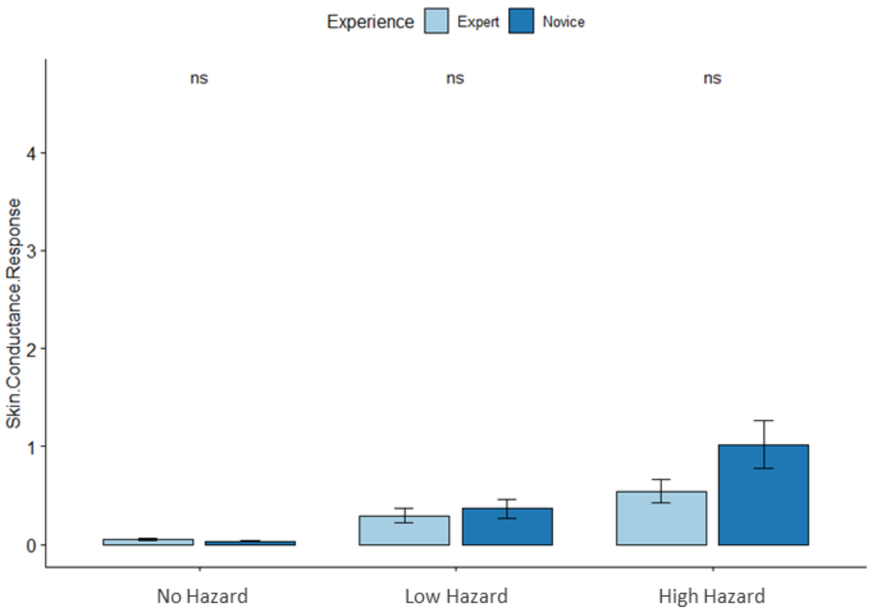

Figure 13. Skin Conductance Response (SCR)

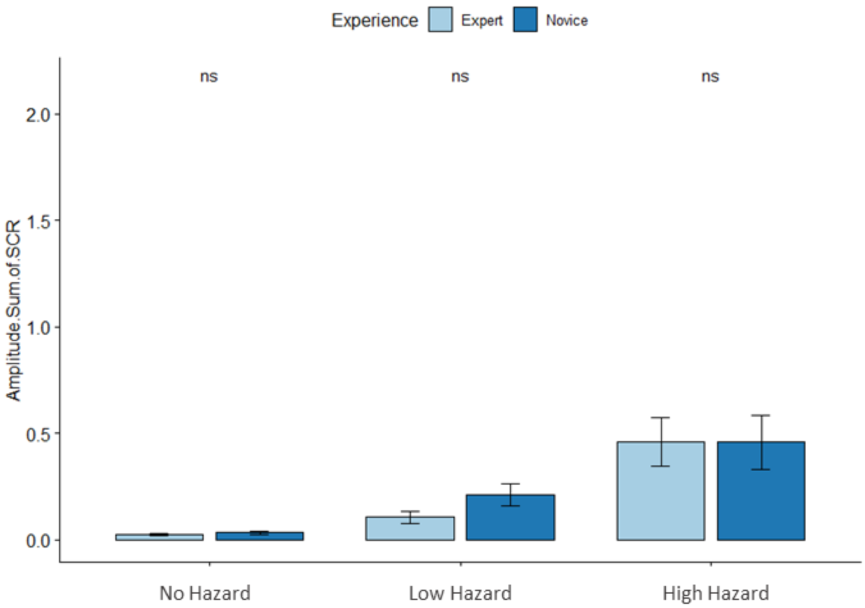

Figure 14. Amplitude Sum of SCR

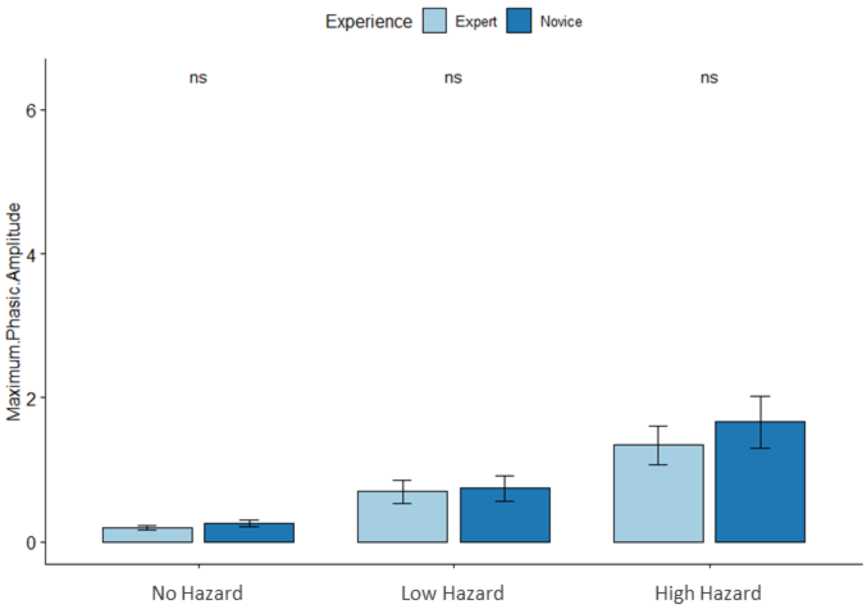

Figure 15. Maximum Phasic Amplitude

Subjective Measure: Situational Stress

The mean and standard deviations of the variables for the subjective measure of stress per group and condition are presented in Table 8. As can be seen, the general trend showed that the perceived situational stress increases as the level of hazard condition increases. Moreover, the experienced group (no hazard = 1.57(±0.86), low hazard = 2.90(±1.21), high hazard = 3.77(±1.04)) exhibited relatively higher perceived stress than the novice group (no hazard = 1.45 (±1.33), low hazard = 1.79(±1.08), high hazard = 2.39(±1.30)).

Table 8. *Descriptive Statistics for Situational Stress*

Group	Condition	Mean (SD) Situational Stress
Novice	No Hazard	1.45 (±1.33)
	Low Hazard	1.79(±1.08)
	High Hazard	2.39(±1.30)
Experienced	No Hazard	1.57(±0.86)
	Low Hazard	2.90(±1.21)
	High Hazard	3.77(±1.04)

Situational stress scores were subjected to a Two-Way Mixed ANOVA having two groups (novice, experienced) and three levels of hazard conditions (no hazard, low hazard, high hazard). All effects were statistically significant at .05 significance level. The main effect of experience yielded an F ratio of $F(1,18) = 5.03$, $p = 0.037$, indicating that the mean scores of perceived situational stress is significantly higher for experienced group (mean = 2.76, sd = 1.38) than the novice group (mean = 1.87, sd = 1.29). On the other hand, the main effect of condition is yielded highly significant results ($F(1,36) = 33.48$). In addition, multiple pairwise comparison with Bonferroni correction indicated that the three conditions were significantly different from each other. More specifically, the drivers reported significantly higher perceived stress in the high hazard condition (mean = 3.05, sd = 1.36), followed by low hazard (mean = 2.32, sd = 1.27) and no hazard (mean = 1.49, sd = 1.12) being the least.

Table 9. *ANOVA Summary Table for Stress Levels: Situational Stress*

	Situational Stress
Experience (E)	$F(1,18) = 5.03$ *
Condition (C)	$F(1,36) = 33.48$ ***
E × C	$F(1,36) = 5.96$ **

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

An interaction effect between experience and condition was also evident ($F(1,36) = 5.96$, $p = 0.002$), indicating that the main effect of experience is greater in the high hazard ($F(1,57) = 20.494$, $p < 0.001$) and low hazard ($F(1,59) = 20.293$, $p < 0.001$) condition than in the no hazard condition ($F(1,61) = 0.155$, $p = 1.0$).

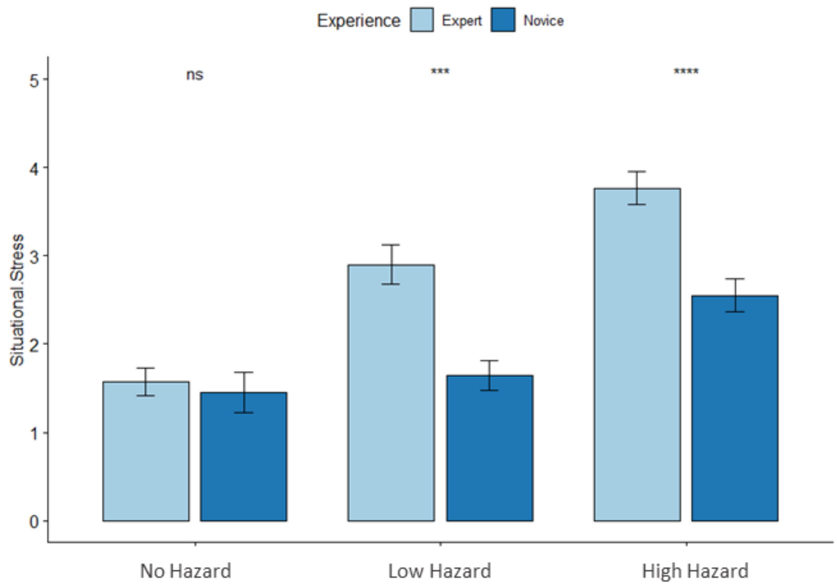

Figure 16. Situational Stress

3.3.3 Attentional Functions

The results for the attentional functions are divided into two parts namely the eye-tracker metrics and subjective measures.

The mean and standard deviations for all the eye-tracker metrics are summarized in Table 10. AOI 1 (area of interest) refers to the front view, AOI 2 refers to the left and right views while AOI 3 refers to the speedometer (see Figure 2). The unit for all AOI-based metrics are in seconds (s). Fixation count and mean fixation duration were normalized relative to the total fixation count and mean fixation duration within the time-of-interest. This is done to minimize any probable individual differences in terms of eye movement behavior.

The results of the Two-Way Mixed ANOVA revealed that experience did not have any significant main effect on fixation count across all AOIs (AOI 1: $F(1,15) = 0.63$, $p = 0.439$; AOI 2: $F(1,14) = 0.264$, $p = 0.615$; AOI 3: $F(1,15) = 4.288$m $p = 0.056$). Similarly, the main effects of condition on the fixation count for AOI 1 ($F(1,30) = 2.616$, p = 0.089) and AOI 3 ($F(1,30) = 2.3900$, $p = 0.388$) were not found. However, the main effect of condition was evident for AOI 2 ($F(1,28) = 30.221$, $p < 0.001$), which indicates that there were significantly higher fixation counts for both experienced and novice drivers in high hazard condition (mean = 0.20, sd = 0.15) than the low hazard condition (mean = 0.09, sd =0.11) and no hazard condition (mean = 0.06, sd = 0.07). Interaction effects were also found for AOI 2 ($F(1,30) = 4.479$, $p = 0.02$) but not for AOI 1 ($F(1,30) = 1.638$, $p = 0.211$) and AOI 3($F(1,30) = 0.975$, p = 0.388). Post-hoc analyses showed that the main effect of experience on the fixation count for AOI 2 was only significant in the high hazard condition ($F(1,47) = 3.245$, $p = 0.07$).

Table 10. *Descriptive Statistics for Attention Functions: Eye Tracker Metrics*

Group	Condition	Mean (SD)							
		Fixation Count (s)			Average Fixation Duration (s)			Time to First Fixation (s)	Horizontal Search
		AOI 1	AOI 2	AOI 3	AOI 1	AOI 2	AOI 3	AOI 2	
Novice	No Hazard	0.623 (±0.13)	0.053 (±0.07)	0.198 (±0.14)	0.592 (±0.22)	0.044 (± 0.03)	0.042 (±0.02)	1.79 (±1.64)	48.541 (±21.53)
	Low Hazard	0.592 (±0.15)	0.11 (±0.12)	0.208 (±0.12)	0.047 (±0.03)	0.027 (±0.02)	0.024 (± 0.01)	2.137 (± 2.68)	42.272 (±18.36)
	High Hazard	0.538 (±0.20)	0.194 (±0.19)	0.155 (±0.11)	0.065 (±0.02)	0.057 (±0.03)	0.037 (±0.02)	1.74 (±2.41)	46.019 (± 17.59)
Experienced	No Hazard	0.546 (±0.14)	0.084 (±0.08)	0.262 (±0.13)	0.063 (±0.03)	0.031 (±0.02)	0.04 (±0.02)	1.637 (±1.41)	46.288 (± 23.65)
	Low Hazard	0.592 (±0.11)	0.068 (±0.09)	0.237 (±0.12)	0.053 (±0.03)	0.047 (±0.04)	0.04 (±0.02)	1.703 (±2.29)	40.784 (±22.75)
	High Hazard	0.5 (±0.12)	0.208 (±0.09)	0.209 (±0.12)	0.074 (±0.03)	0.057 (± 0.03)	0.053 (±0.03)	1.699 (±2.36)	43.895 (±27.25)

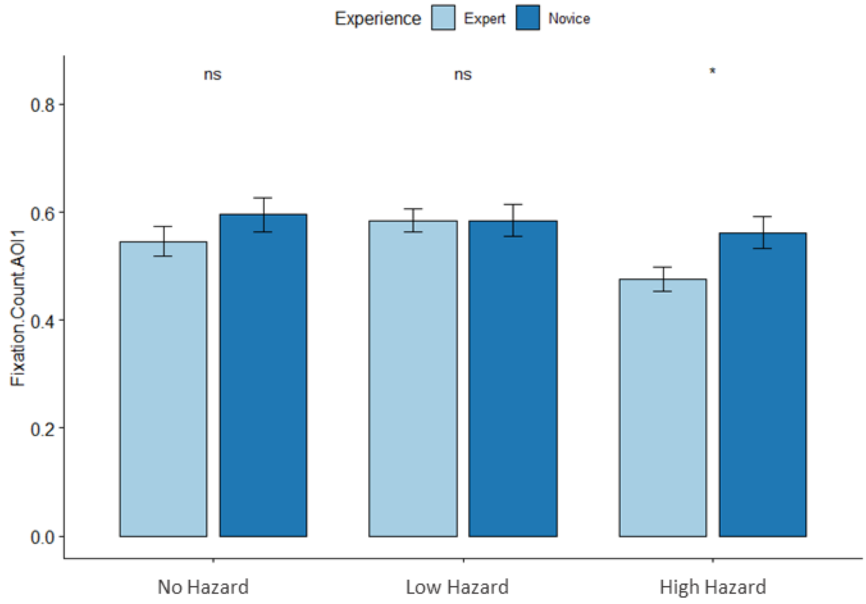

Figure 17. Fixation Count (AOI 1: front view)

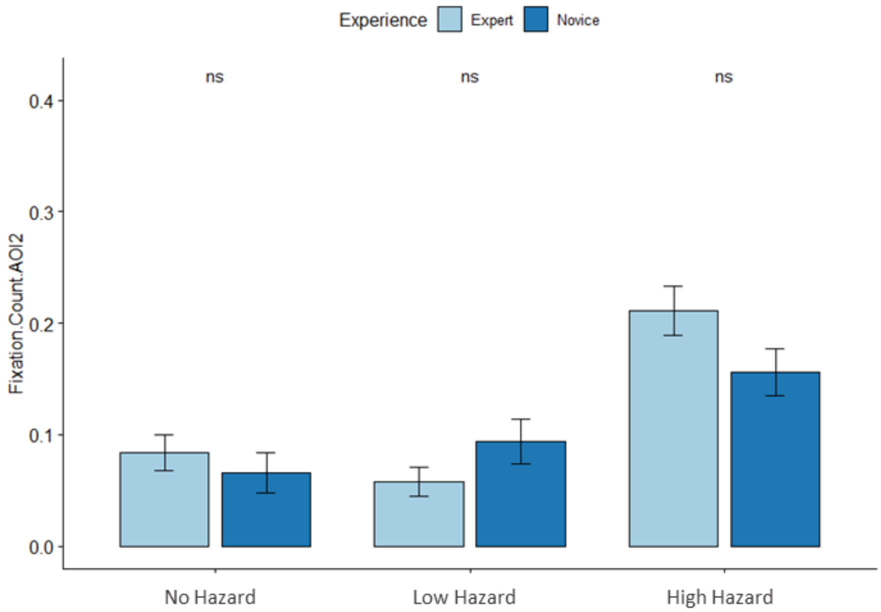

Figure 18. Fixation Count (AOI 2: side view)

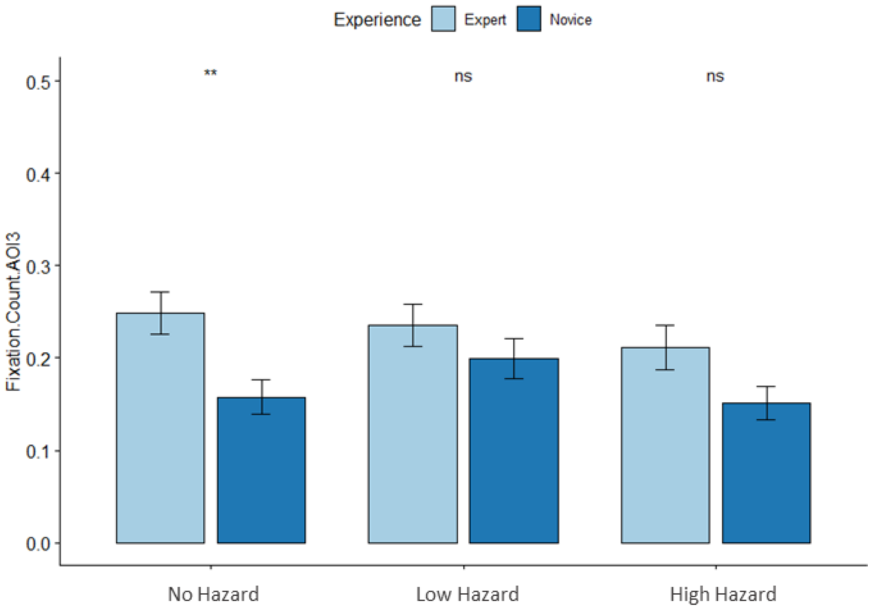

Figure 19. Fixation Count (AOI 3: speedometer)

In terms of the average fixation duration, the results revealed that the main effect of experience is only evident on AOI 3 ($F(1,15) = 5.461$, p = 0.033), and not in AOI 1 ($F(1,15) = 1.264$, p = 0.278) and AOI 2 ($F(1,14) = 0.058$, p = 0.813). This means that the experienced group had higher average fixation duration on the speedometer compared to the novice group. In contrast, condition yielded highly significant main effects on average fixation duration across all the AOIs (AOI 1: $F(1,30) = 15.575$, $p < 0.001$; AOI 2: $F(1,28) = 9.442$, $p < 0.001$; AOI 3: $F(1,30) = 8.992$, $p < 0.001$). For AOI 1, post-hoc pairwise analysis revealed that each condition is significantly different from each other, with high hazard condition (mean = 0.07, sd = 0.03) having the longest average fixation duration, followed by no hazard (mean = 0.06, sd = 0.02) and low hazard condition (mean = 0.05, sd = 0.03). As for AOI 2, there were no significant difference between the no hazard (mean = 0.04, sd = 0.03) and low hazard conditions (mean = 0.4, sd = 0.03), but the mean fixation duration appeared to be far longer during the high hazard condition (mean = 0.07, sd = 0.03). Contrarily, in AOI 3, the mean fixation duration is far shorter in the low hazard condition (mean = 0.03, sd = 0.01) than both no hazard (mean = 0.04, sd = 0.02) and high hazard condition (mean = 0.05, sd = 0.03).

Nevertheless, there were no interaction effects in terms of average fixation duration across all the AOIs (AOI 1: $F(1,30) = 15.575$, $p < 0.001$; AOI 2: $F(1,28) = 9.442$, $p < 0.001$; AOI 3: $F(1,30) = 8.992$, $p < 0.001$).

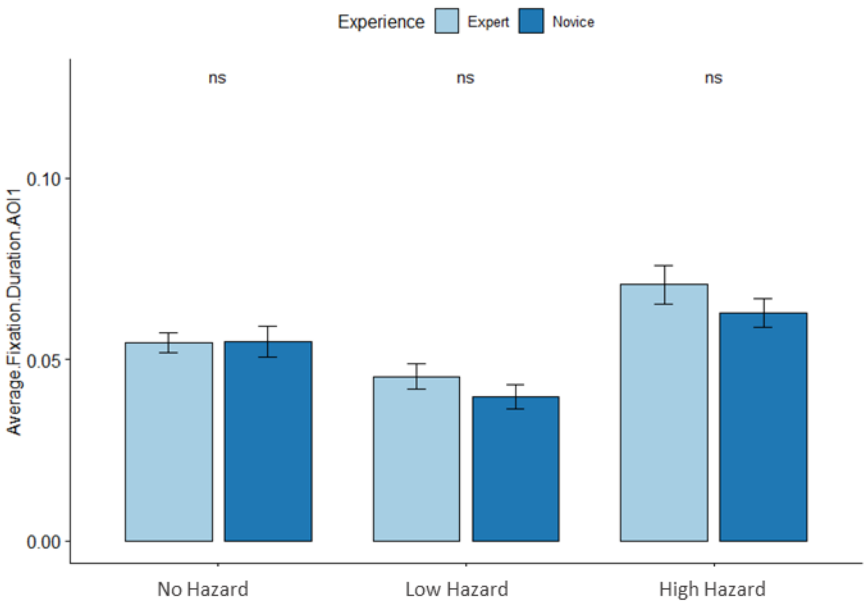

Figure 20. Average Fixation Duration (AOI 1: front view)

Table 11. *ANOVA Summary Table for Attentional Functions: Eye-Tracker Metrics*

	Fixation Count			Average Fixation Duration			Time-to-First Fixation	Horizontal Search
	AOI 1	AOI 2	AOI 3	AOI 1	AOI 2	AOI 3	AOI 2	
Experience (E)	$F(1,15)=0.631$	$F(1,14)=0.264$	$F(1,15)=4.288$.	$F(1,15)=1.264$	$F(1,14)=0.058$	$F(1,15)=5.461$*	$F(1,15)=5.340$*	$F(1,15)=0.791$
Condition (C)	$F(1,30)=2.616$.	$F(1,28)=30.221$***	$F(1,30)=2.390$	$F(1,30)=15.575$***	$F(1,28)=9.442$***	$F(1,30)=8.992$***	$F(1,30)=2.394$	$F(1,30)=1.382$
E × C	$F(1,30)=1.638$	$F(1,28)=4.479$*	$F(1,30)=0.975$	$F(1,30)=0.488$	$F(1,28)=3.095$.	$F(1,30)=2.385$	$F(1,30)=3.591$*	$F(1,30)=0.841$

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

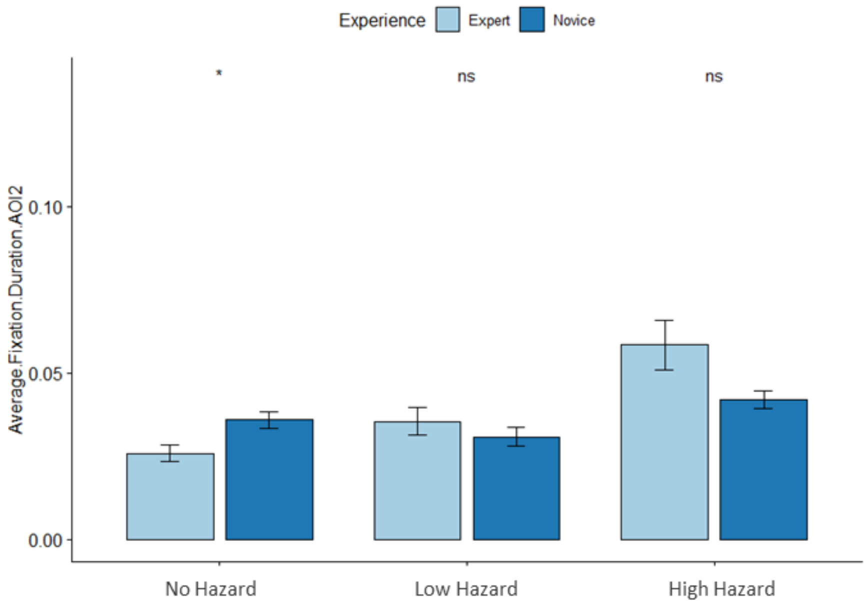

Figure 21. Average Fixation Duration (AOI 2: side view)

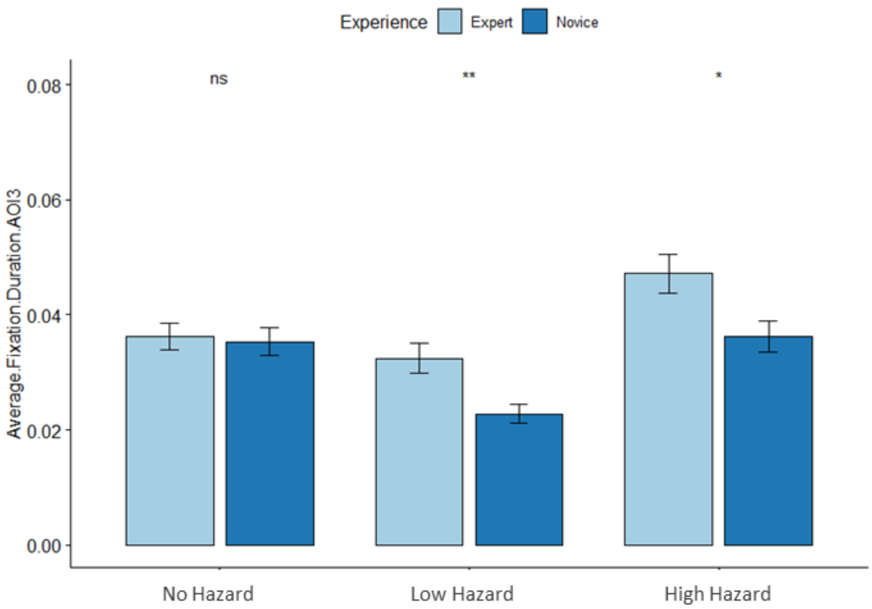

Figure 22. Average Fixation Duration (AOI 3: speedometer)

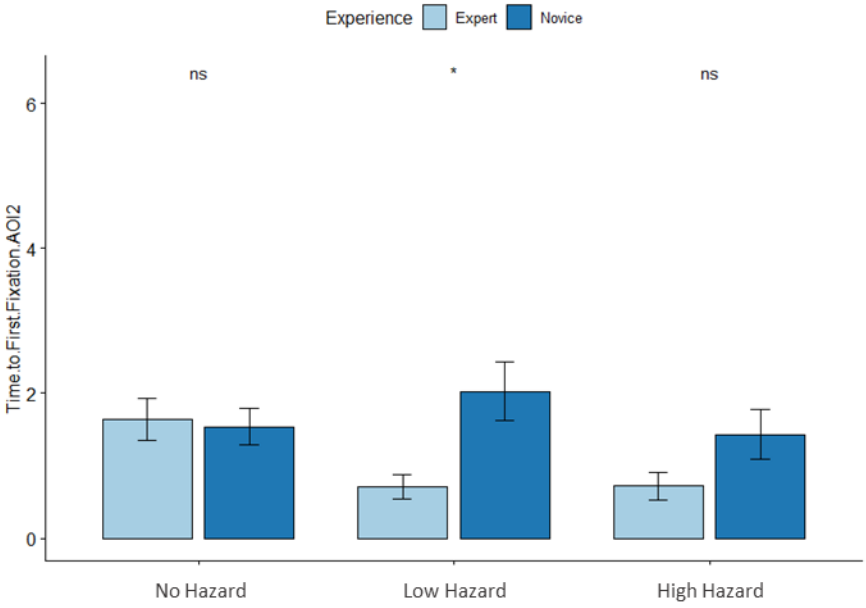

Figure 23. Time to First Fixation (AOI 2: side view)

Results of the analyses also found that experience had a significant main effect on the time to first fixation for AOI 2 ($F(1,15) = 5.340$, $p = 0.035$). This result indicates that the experienced group (mean = 1.69, sd = 2.01) fixated to either the left or right side significantly faster than the novice group (mean = 1.90, sd = 2.26). Although the main effect of condition was not evident ($F(1,30) = 2.394$, $p = 0.108$), an interaction effect was found for both experience and condition ($F(1,30) = 3.591$, $p = 0.039$). Particularly, the main effect of experience was most apparent in the low hazard condition ($F(1,44) = 7.463$, $p = 0.027$) and least evident in the no hazard condition ($F(1,47) = 0.067$, $p = 1.0$).

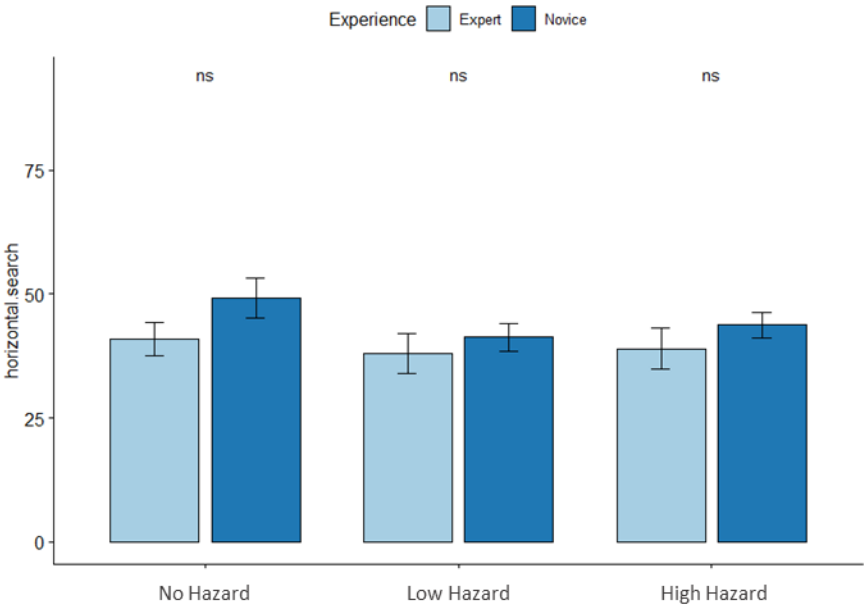

Figure 24. Horizontal Spread of Search

In terms of horizontal spread of search, the main effect of experience ($F(1,15) = 0.791$, $p = 0.387$) and condition ($F(1,30) = 1.382$, $p = 0.266$) appeared to be both insignificant. Similarly, the interaction effect was also non-significant ($F(1,30) = 0.841$, $p = 0.441$).

(a) (b
)

Figure 25. Sample gaze plot of (a) novice and (b) expert in no hazard condition

(a) (b
)

Figure 26. Sample gaze plot of (a) novice and (b) expert in low hazard condition

(a) (b
)

Figure 27. Sample gaze plot of (a) novice and (b) expert in high hazard condition

(a) (b)

Figure 28. Sample heat map of (a) novice and (b) expert in no hazard condition

(a) (b)

Figure 29. Sample heat map of (a) novice and (b) expert in low hazard condition

(a) (b)

Figure 30. Sample heat map of (a) novice and (b) expert in high hazard condition

Subjective measure: General Attention Load

The mean and standard deviations of the variables for the subjective measure of attention load per group and condition are presented in Table 12. As can be seen, the general trend showed that the perceived attention load increases as the level of hazard condition increases. Moreover, apart from the no hazard condition which yielded the same mean scores for both novice (mean = 1.70, sd = 1.40) and experienced group (mean = 1.70, sd = 0.84), the experienced group (low hazard = 3.00(±0.98), high hazard = 3.77(±0.73)) exhibited relatively higher perceived attention load than the novice group (low hazard = 1.94(±1.22), high hazard = 2.39(±1.34)).

Table 12. *Descriptive Statistics for General Attention Load*

Group	Condition	Mean (SD) Attention Load
Novice	No Hazard	1.70(±1.40)
	Low Hazard	1.94(±1.22)
	High Hazard	2.39(±1.34)
Experienced	No Hazard	1.70(±0.84)
	Low Hazard	3.00(±0.98)
	High Hazard	3.77(±0.73)

General attention load scores were subjected to a Two-Way Mixed ANOVA having two groups (novice, experienced) and three levels of hazard conditions (no hazard, low hazard, high hazard). All effects were statistically significant at .05 significance level. The main effect of experience yielded an F ratio of $F(1,19) = 4.944$, $p = 0.038$, indicating that the mean scores of perceived attentional load is significantly higher for experienced group (mean = 2.84, sd = 1.20) than the novice group (mean = 2.01, sd = 1.34). On the other hand, the main effect of condition is yielded highly significant results ($F(1,38) = 43.152$, $p < 0.001$). In addition, multiple pairwise comparison with Bonferroni correction indicated that the three conditions were significantly different from each other. More specifically, the drivers reported significantly higher perceived stress in the high hazard condition (mean = 3.05, sd = 1.29), followed by low hazard (mean = 2.44, sd = 1.23) and no hazard (mean = 1.69, sd = 1.16) being the least.

Table 13. *ANOVA Summary Table for Attentional Functions: General Attention Load*

	Attention Load
Experience (Exp)	$F(1,19) = 4.944$ *
Condition (Con)	$F(1,38) = 43.152$ ***
Exp × Con	$F(1,38) = 11.029$ ***

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

An interaction effect between experience and condition was also evident ($F(1,38) = 11.029$, $p < 0.001$), indicating that the main effect of experience is greater in the high hazard ($F(1,57) = 24.661$, $p = 0.002$) and low hazard ($F(1,58) = 13.263$, $p = 0.002$) condition than in the no hazard condition ($F(1,61) = 0.0001$, $p = 1.0$).

Chapter 4

Discussion

The goal of this study is to investigate the differences in stress-levels and attentional functions between experienced and novice drivers during intersection-related hazard situations. In this driving simulation study, stress-levels and attentional functions were assessed through psychophysiological and subjective measures. In general, the results revealed palpable and interesting differences between the two groups. Contrary to what is expected, the results of the experiment showed that experienced drivers exhibited higher levels of stress during intersection-related hazard situations than novice drivers. Furthermore, experts showed proportional attention allocation to both the primary task and hazard stimulus during high hazards situations than novice drivers. Details of the findings for each measure are discussed below.

4.1 Driving Performance

Results of the driving simulation experiment revealed that the driving performance of both experienced and novice drivers in terms of speed and lane deviation is fairly indistinguishable. Although the graphical trend (see Fig. 6) showed that experienced drivers exhibited slightly lesser lane deviation, the difference is not that apparent. This slight difference may indicate that hazard exposure has a limited impact on experienced drivers than novices in terms of lane keeping. Overall, this finding goes in line with the studies that found that on-road direction control and speed choice is not fully dependent on the amount of driving experience, but rather it is a skill that can be easily acquired even through a small amount of training (Isler et al., 2011). Thus, given enough training, being able to execute basic vehicle control tasks such as lane keeping and speed control is considered fundamental for all drivers regardless of the length of driving experience.

On the other hand, as expected, the driving performance of both groups declined as the level of the hazard increased. Moreover, further analysis showed that the increase in both speed and lane deviation became strongly evident with just the mere presence of a hazard situation, regardless of its level. Drivers from both groups tend to slow down and move away from the incoming vehicle during the low and high hazard conditions. Similar to the findings of the previous studies, hazard exposure while driving directly affect vehicle control and driving performance (Kaber et al., 2012).

4.2 Stress Level

In terms of stress levels, results from the analysis of the electrocardiogram (ECG) signals revealed that experienced drivers showed significantly lower levels of standard deviation of R-to-R intervals (SDRR), mean squared difference of successive normal-to-normal intervals (RMSSD) and high-frequency (HF) than the inexperienced drivers. This means that opposite of being in accordance with the initial assumption, experienced drivers exhibited higher levels of stress than novice drivers during intersection-related hazard situations. Low levels of SDRR, RMSSD and HF of experienced drivers signal instantaneous stress response which indicates that experienced drivers were in the fight-or-flight mode while crossing the intersection in the simulation experiment. This increase in stress among experienced drivers can be attributed to the heightened mental workload prompted by perceived risk brought by the hazard situation. With this result, it can be inferred that experienced drivers showed more evident physiological changes upon hazard exposure.

On the other hand, novice drivers appeared to be more relaxed and less stressed across all conditions. The lack of physiological stress response despite the presence of a hazard situation may suggest that the novice drivers failed to recognize the potential risk brought by the hazard situation while crossing the intersection. The lack of experience and underdeveloped mental model for intersection-related risks can be one of the causes of the passiveness of inexperienced drivers. Although this result seems to contradict the previous findings where novices are more susceptible stress while driving (e.g. Nabatilan et al., 2011), it is possible however that novice drivers can still be more susceptible to error-producing stress when executing different driving tasks. From the previous studies, the stress experienced by novices is caused by dual or multiple tasks (Nabatilan et al., 2011). Since novices tend to lack automation in some aspects of driving, they experience more stress in driving scenarios involving multiple tasks in addition to driving. However, in the present study which did not involve any driving-unrelated tasks, it is possible that the novices were not able to feel any stress because of the inability to recognize the risks involved and anticipate the probability of executing additional actions in response to the hazard. It is probable that they were not able to pay attention to the hazard stimulus enough to affect their physiological state and mental workload.

However, although there were differences between groups, levels of stress did not differ across conditions. This means that even in an event where there is no hazard present, the experienced group generally had greater physiological stress response than the novice group. This could be explained by the context and nature of the experiment. Since intersections are generally dangerous and are considered to be highly accident-prone areas (US Department of Transportation, 2010), it is possible that only drivers with enough experience are able to recognize the increased probability of risk in this context. Thus, even in no hazard condition, experienced drivers exhibited higher levels of stress than novice drivers because of the mere fact that they are crossing an intersection.

Furthermore, results from the electrodermal response (EDA) analysis revealed that the increase in the level of hazard condition is proportional to the increase in skin conductance response (SCR), amplitude sum of SCR and maximum phasic amplitude of the drivers. Further analysis also showed that the increase in EDA is more apparent in the high hazard situation than both no hazard and low hazard conditions. This finding validates that the high hazard situation is indeed perceived to be dangerous that it was able to elicit a remarkable physiological response from the sympathetic nervous system.

However, the results did not find any significant difference in the EDA response of experienced and novice drivers. The differences in the results of ECG and EDA might be caused by the difference in the nature of the physiological response being measured. It could be that ECG functions as a measure of state stress whilst EDA function as a measure of acute stress. ECG was able to capture group differences as it accounts for the subjects' stress or emotional state throughout the whole event. Meanwhile, EDA was able to capture differences between conditions because of the sudden appearance of an incoming vehicle induced intense emotional fluctuations. Nevertheless, this assumption with regards to how ECG and EDA function as a measure of stress warrants further investigation.

The analysis of the subjective measure indicates that experienced drivers perceived significantly higher levels of stress than novice drivers across all conditions. Particularly, although there were no actual differences between the two groups in perceived stress during the absence of a hazard situation, the difference in the perceived stress between experienced and novice drivers grow larger as the level of hazard increases. This suggests that experienced drivers are more sensitive to changes in driving conditions, more specifically in the presence of a possible threat. This result supports the notion of previous studies which suggest that risk perception differs as a function of experience (Pradhan et al., 2009). In the experiment, it is possible that experienced drivers were able to recognize the threat thus had more obvious conscious response towards it. Meanwhile, it is also viable to infer that novice drivers exhibited less stress both physiologically and in perception because they were not able to appropriately judge and anticipate the hazard situation effectively due to the lack of experience. Moreover, as previous studies have claimed learner drivers tend to be overconfident with their driving skills (Liu et al., 2009). This could also be one of the reasons why novice drivers experienced less stress despite the presence of an on-road threat.

4.3 Attentional Function

Results from the eye-tracking metrics showed that during hazard situations experienced drivers had a shorter time-to-first fixation on AOI 2, which is the hazard event-related area of interest. This means that in contrast to novice drivers experienced drivers are faster in attending to threatening stimuli. It is probable that experienced drivers are equipped with a wider peripheral visual field which enabled them to fixate to a stimulus within the periphery quicker than their counterparts. Studies have claimed that experienced drivers are more inclined and are more capable of using their peripheral vision to monitor events on the road (Underwood et al., 2003). Moreover, it is also often claimed that experienced drivers tend to notice threat-related stimulus quicker because of the efficient filtering of information from the environment (Pemmer et al., 2018). In general, experienced drivers are better in prioritizing which tasks to attend to in any given situation. Furthermore, shorter time-to-first fixation on

AOI 2 of experienced drivers might also be influenced by the anticipation of a probable threat in an intersection. As mentioned before, road intersection is in itself considered to be a danger zone. Thus, experienced drivers with better prior knowledge are more likely to prepare for the potential hazards that may arise in an intersection.

In terms of fixation count, condition had an effect on the fixation count for AOI 2 (side view). Since AOI 2 represents the hazard event-related AOI it is expected that the presence of a threat-related stimulus would attract attention and increase the number of fixations within that area. But what is perhaps more noteworthy is that the hazard conditions and driving experience had an interaction effect on the fixation count for AOI 2. Although the two groups did not have any significant difference in the number of fixation count for AOI 2 in no hazard and low hazard condition, the gap significantly increased during high hazard condition where experienced drivers had more fixations. This could imply that experienced drivers allocated more of their attention to the threat-related stimulus especially during highly threatening situations. Moreover, given that experienced drivers had longer fixation duration on AOI 3 (speedometer) during hazard conditions, it is viable to assume that experienced drivers are able to allocate more attention to threat-related stimuli (AOI 2) while maintaining focus on task-related areas of interest (e.g. speedometer). Whereas for novice drivers, attending to the threat-related stimuli served as a secondary task with which their lower mean fixation duration in task-related AOI suggests that they tend to quickly move from one focus to the next.

Results also showed the mean fixation duration significantly differed across conditions. However, the difference is rather intriguing in a sense that during low hazard condition task-related AOIs (front view and speedometer) had shorter average fixation duration in comparison with both no and high hazard. This means that drivers of both groups quickly move one's focus to another for task-related AOIs during low hazard condition. Moreover, as one would expect, during high hazard condition there were significantly longer mean fixation duration for AOI 2. This could mean that high hazard situation required longer time for drivers to processes information.

On the other hand, experience nor condition did not yield any effect on the horizontal spread of search. One possible reason for this insignificant finding is that the simulation set-up only involved a simple route with three intersections. Since road complexity was not part of the present research' interest, the simulation setting was designed to be plain and uncluttered. Thus, horizontal visual scanning may not be needed for this kind of road setting. However, as can be seen from the sample gaze plots and heatmaps (see Fig 25-30.). There are slight and trivial differences between the gaze patterns of experienced and novice drivers. This interesting visually observable differences account for further analysis to be interpreted objectively.

Lastly, the results of the subjective measures showed that experienced drivers had higher perceived attention load during hazard situations. The difference between the two groups intensifies as the level of hazard increases. This may imply that experienced drivers are generally more sensitive and conscious during hazard exposure. They tend to be more aware of the fact that the situation calls for additional attention. Meanwhile, novice drivers do not seem to exhibit the sensitivity to hazard situations as much as experienced drivers. This result suggests that sensitivity and attentiveness to risky situations may only be developed through the accumulation of driving experience.

Chapter 5

Conclusion

5.1 Conclusion

The main aim of this study is to determine the differences in stress-level and attentional functions between experienced and novice drivers during intersection-related hazard situations. Stress levels and attentional functions were measured through both psychophysiological measurements and subjective questionnaires to acquire a more in-depth data. In summary, it was found that experienced drivers are more sensitive to changes and threats in the environment while driving. Moreover, experienced drivers experience higher levels of stress than novice drivers during hazard situations in 4-way intersections. However, despite the increased stress the experienced drivers' driving performance and attentional functions were not affected negatively. Instead, experienced drivers exhibited better attention allocation by attending to both the threatening stimuli and task-related AOIs (e.g. front view and speedometer). On the other hand, novices tend to be more relaxed and unbothered by hazard situation as evidenced by the lack of physiological responses. In general, the results revealed palpable and interesting differences between the two groups.

5.2 Limitation, Contribution and Future Direction

The current study provided insightful inferences with regards to the difference of experienced and inexperienced drivers in a more specific level. Moreover, it provided great contribution to the literature by utilizing multimodal psychophysiological measurements in measuring stress-levels and attentional functions in a simulation experiment. However, like any other study, the present research is not without its limitations. Since the task and the simulation environment is simple, highly discernable differences were rather hard to uncover. It would be better for future studies to consider testing in different driving environment with varying level of environmental complexity in order to gather more insights with regards to the real difference between groups. Moreover, considering the fidelity of the driving simulation environment, future studies can investigate the effects of driving game experience as a probable mediator to driving performance during simulation.

Also, future studies may include additional performance measures such as crash-related measurements for more insights regarding the effects of hazards in intersections.

Another limitation of the present research is that, the data from the eye-tracking device was rather underutilized. More advanced eye-tracking analyses would have helped get better insights with regards to the actual effect of experience on the drivers' attentional functions. Additional analyses such as pupillary analysis and scan path analysis can be considered for future research.

By and large, the results of the present study revealed interesting differences between the stress levels and attentional functions of experienced and novice drivers. These findings can serve as a groundwork for further studies regarding the effects of driving experience in overall driving performance and driving-related higher-order skills. The results of this study may also be applied in designing more effective training modules and driver support systems that would help drivers specifically during intersection-related hazard situations.

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국문초록

본 연구의 목적은 교차로와 관련된 위험 상황 하에서 운전 경험의 수준이 다른 운전자 간 스트레스 수준과 주의 능력의 차이를 확인하는 것이다. 운전 빈도 및 기간에 따라 숙련된 운전자와 미숙한 운전자의 두 그룹으로 분류된 운전면허 자격을 보유한 21명의 운전자들 (남성 15명, 여성 6명, 평균 27.71 ± 3.62세)을 대상으로 차량 시뮬레이터를 활용한 실험이 수행되었다. 실험참여자들은 세 가지 위험 상황 조건(무위험, 저위험, 고위험)이 임의로 제시되는 환경에서 동일 차선을 유지하여 정속 주행하는 과업을 9회 반복 수행하였다. 과업이 수행되는 동안 ECG, GSR, 그리고 시선 추적 데이터가 수집되었고, 과업 수행 종료 후 주관적 설문지를 활용하여 인지된 스트레스 및 주의 부하가 측정되었다. Mixed-ANOVA 수행 결과, 운전 수행도는 차선 이탈 및 속도 이탈 측면에서 위험 상황 조건 별 유의한 차이가 있었으나($p < 0.001$), 운전 경험 그룹 간의 차이는 없었다. 또한, GSR 척도(SCR, Sum of Amplitudes, Phasic Max)는 위험 상황 수준이 증가할수록 스트레스가 점진적으로 증가하는 것으로 확인할 수 있었으나, 운전 경험 그룹 간의 차이는 없었다. 반면, ECG 척도(STD RR, RMSSD, HF)는 숙련된 운전자 그룹이 미숙한 운전자 그룹보다 교차로 관련 위험 상황 동안 더 높은 스트레스를 나타낸다는 것을 보여주었다. 한편, 주의 능력 측면에서 AOI와 non-AOI 기반의 시선 추적 척도(fixation count, mean fixation duration, time-to-first-fixation and horizontal dispersion)는 위험 상황 조건 별 유의한 차이가 있었으나, 운전 경험 그룹 효과는 time-to-first-fixation에서만 나타났다. 이는 숙련된 운전자 그룹이

미숙한 운전자 그룹보다 위험 자극에 대해 상대적으로 신속하게 반응하기 때문인 것으로 판단된다. 게다가, mean fixation duration에서는 운전 경험과 위험 상황 조건의 교호작용 효과 또한 확인할 수 있었다. 숙련된 운전자 그룹은 미숙한 운전자 그룹보다 고위험 상황 하에서 주요 과업과 위험 자극 모두에 비례적으로 주의를 할당하는 것으로 나타났다. 숙련된 운전자 그룹이 미숙한 운전자 그룹보다 위험 상황 조건이 변함에 따라 스트레스 수준과 주의 부하의 변화가 더 심하다는 것을 나타내는 심리생리학적 척도들의 분석 결과는 주관적 설문지의 분석 결과를 통해 보다 확증되었다. 주관적 설문지의 결과 또한 숙련된 운전자 그룹이 미숙한 운전자 그룹보다 위험 상황 조건의 변화에 스트레스와 주의 능력 측면에서 보다 민감하다는 것을 보여주었다. 본 연구의 실험 결과는 숙련된 운전자와 미숙한 운전자의 두 그룹 간 뚜렷하면서 흥미로운 차이를 보여주었으며, 향후 교차로 관련 위험 상황 하에서 운전자의 안전에 도움을 줄 수 있는 지원 시스템과 효과적인 훈련 모듈을 설계하는 데 활용될 수 있을 것으로 기대된다.

Keywords: 운전 경험, 스트레스, 주의 능력, 생체 신호

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