Hazard Perception Performance and Visual Scanning Behaviours: The Effect of Sleepiness

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Highlights

- Young adults are more susceptible to the effect of sleepiness
- Sleepiness impaired hazard perception performance with greater impairment with time-on-task
- Decrements in the range of horizontal and vertical scanning also occurred
- Moderate sleep restriction produced concerning performance impairments

Abstract

Driver sleepiness accounts for a substantial proportion of crashes in Australia and Worldwide. Young adults are overrepresented in sleep-related crashes and are more susceptible to sleepiness, resulting in impaired attention and driving performance. Visual scanning behaviour can affect the role between attention and information acquisition from the driver's environment. Thus, if attention is impaired, visual scanning behaviours are likely to show decrements as well. Overall, 32 young adults aged between 20-25 years completed a 60-minute hazard perception task to examine the effect of sleepiness and time-on-task on hazard perception performance, visual scanning behaviours, subjective sleepiness scores, and psychomotor vigilance test performance. The main outcomes include decrements in hazard perception performance and a restriction in horizontal and vertical eye scanning ranges across the 60-minute session, but with a more pronounced effect when sleep-restricted. These outcomes were consistent with increases in subjective sleepiness and behavioural metrics of sleepiness assessed via the PVT. Reductions in scanning range could limit opportunities to attend to hazards and other critical safety events. The current study outcomes provide an important contribution regarding the risks associated with sleepy driving performance.

Keywords: eye tracking; hazard perception, sleep restriction; young drivers

1. Introduction

Experiencing sleepiness results in impaired neurobehavioral and cognitive functioning (Nilsson et al., 2005; Smith et al., 2002) as well as decreased cortical arousal (Watling et al., 2016). Experiencing sleepiness while driving is commonly reported by drivers and is associated with increased likelihood of having a sleep-related close call (Watling et al., 2020) as well as increased crash risk (Åkerstedt et al., 2008). Thus, driver sleepiness is recognised as a significant contributor to road crashes.

Young drivers (< 25 years) are disproportionately involved in sleep-related crashes (Connor et al., 2002). There are several factors that can contribute to young drivers' disproportionate involvement in sleep-related crashes. These contributing factors include sleep-related issues (Åkerstedt et al., 2008) as well as psychological factors such as lower perceived risk which could encourage drivers to drive while sleepy (Watling et al., 2015). Perhaps the most critical factor relates to young adults being more susceptible to the impairments associated with sleepiness than mature adults. For instance, younger drivers exhibit greater susceptibility to impairments when participating in vigilance-based tasks (Zitting et al., 2018) than mature adults. As such, taking into consideration young drivers' overrepresentation in crashes, including sleep-related crashes, the evidence suggests that this age group is more likely to experience an impairment in critical driving skills in addition to exhibiting a greater susceptibility to sleepiness.

An important driving skill linked with crash risk is hazard perception. Hazard perception is a driving skill used to anticipate traffic situations that may result in a crash or near miss. Efficient hazard perception is reliant on the driver's perceptual capabilities (Underwood, 2007), their attentional functioning and capacity and cognitive processing of on-road stimuli (Wetton et al., 2010). These combined aspects suggest hazard perception is a multi-component process that requires high-order cognitive resources.

1.1 Hazard Perception and Perceptual Capabilities

Hazard perception is contingent on perceptual capabilities. Specifically, poor scanning of the roadway limits the available information that the driver can process and increases the likelihood of a crash or close call (Klauer et al., 2006). Despite the importance of perceptual capabilities with hazard perception and the likelihood of a crash, limited studies are available on the effect of extended driving times (i.e., time-on-task) on hazard perception and perceptual behaviours. Most of these studies examining perceptual behaviours with extended driving have largely focused on variations of saccades and fixation durations. Several studies have noted increases in driving times results in decreases in saccade (Ahlstrom et al., 2013; Cazzoli et al., 2014; Schleicher et al., 2008) and microsaccade velocities (Di Stasi et al., 2015), and have been interpretated as a general decrease in attention and engagement with the visual stimuli. Considered together, the effect from decreases in arousal (experiencing sleepiness and time-on-task effects) appears to be associated with a general slowing of eye-related behaviours and more variability of scanning of the visual scene.

Studies have reported inconsistent findings, particularly with regards to the effect of decreases in arousal from sleepiness and time-on-task effects on a few perceptual behaviours. For instance, Cazzoli et al. (2014) describes increases in fixation durations while performing visual tasks when participants' arousal levels were low based on their chronotype assessment. However, variations in fixation rate due to decreases in arousal have been inconsistent. For instance, decreases in fixation rate with increased driving time and time-on-task when sleep deprived have been reported in a few studies (i.e., Lavine et al., 2002; Shiferaw et al., 2018), while increases in the fixation rate of modest duration fixations, those being between 150-900ms (Schleicher et al., 2008), have been noted in other studies. Overall, such inconsistent findings highlight the importance of conducting additional studies to better understand the effects of arousal.

The range of fixations that occur with scanning of the visual scene can be a determinant of hazard perception performance. When the range of visual scanning is restricted, this limits the likelihood of identifying hazards that are in the outmost areas of the visual environment (Underwood et al., 2011). The research noted above highlights the effect of sleepiness with a general slowing of visual scanning behaviours. Shiferaw et al. (2018) noted that the range of fixations in the visual field becomes less ordered and more haphazard with increased driving time when sleep deprived. Also related to range of fixations, Lavine et al. (2002) found fixations to be further away from the target stimuli when task duration increased. However, no effect was found with sleep-deprived pilots concerning the range of their scanning behaviours (Previc et al., 2009). Previous research has established that when cognitive resources are limited (via high attentional workload paradigms), an effect of attentional narrowing occurs, whereby scanning ranges are reduced (Savage et al., 2013). Experiencing sleepiness restricts the number of cognitive resources available and could possibly result in a restriction of scanning range.

The effects of sleepiness as well as time-on-task appears to be associated with a general slowing of visual scanning behaviours and more variable scanning of the driving scene, with the effect on fixations rate equivocal. Younger drivers are known to be over-represented in crashes and, to a greater extent, impaired from the effect of sleepiness. However, relatively little is known about the effect of sleepiness on younger drivers visual scanning behaviours. Understanding how sleepiness impacts on younger drivers scanning of the driving scene and on subsequent hazard perception could have implications for driver training practices and the communication of risk mitigation practices. Thus, the current study sought to determine the effects of decreases in arousal manipulated via sleep restriction and time-on-task effects, for their effects on hazard perception performance and visual scanning behaviours among a sample of younger drivers. The following hypotheses were proposed: (1) time-on-task effects will result in impairments of task performance, visual scanning behaviours and increases in subjective sleepiness; and (2) sleep restriction will, to a larger extent, result in greater impairments in task performance, visual scanning behaviours, and increases in subjective sleepiness when fully alert.

2. Method

2.1 Design

The following study implemented a 2 x 3 within-subjects design. The two independent factors were Sleepiness Level and Time Period. The first factor, Sleepiness Level, comprised an Alert condition (maintain habitual sleep duration) and a Sleepy condition (habitual sleep duration restricted by two hours). Time period, the second factor, entailed three distinct 20-minute time segments (segment one, two, and three) throughout an hour-long hazard perception task. A 2 x 2 repeated ANOVA was also performed to examine the changes in PVT data - the first factor was Sleepiness Level, and the Time Period variable consisted of two sessions (pre- and post- testing). Breaches of the sphericity assumption used the Greenhouse-Geisser correction. Planned comparisons sought to compare segment one and two and segment two and three for the Alert and Sleepy conditions respectively while also comparing the Alert and Sleepy conditions at segments one, two, and three. Assignment of participants to their initial experimental condition (i.e., alert or sleepy condition) and the undertaking of the HPT test version (i.e., test one or two) were counterbalanced.

2.2 Participants

Young adults aged between 20-25 years were invited to take part in the study. Inclusion criterion ensured participants held a valid Australian drivers’ licence and had a minimum of two years of driving experience. In addition, participants were required to have a habitual bedtime no later than 12 midnight; no significant health problems or a sleep disorder, no excessive daytime sleepiness (assessed as a Epworth Sleepiness Scale of > 10: Johns,

1991) or have sleeping difficulties (assessed as a Pittsburgh Sleep Quality Index score of > 5: Buysse et al., 1989); could not be a shift worker; have not travelled overseas in the past month; have not taken prescription medications or illicit drugs that altered arousal levels; or do not drink more than three cups of coffee per day and/or more than two standard drinks of alcohol per day.

Overall, 32 participants (19 women, 13 men) took part in the study. The mean age of participants was 21.47 years (*SD* = 1.24; range = 20-24). All participants were current drivers and held a valid driver's licence, with the mean duration of licensure being *M* = 5.17 years (*SD* = 1.17; range = 4-8). On average, the sample reported having driven 6.28 hours per week (*SD* = 5.28; range = 2-25). Altogether, 10 participants (31.25%) reported having a sleep-related close call (i.e., a near-crash while driving or driving outside of the designated lane); however, no participant reported ever having had a sleep-related crash (i.e., where they were the driver and there was damage to property or persons). All participants were paid 100 AUD for partaking in the study.

2.3 Measures

2.3.1 Hazard Perception Task

Hazard perception skill can be quantified by the amount of time required to identify potential traffic conflicts that may result in a crash or near miss. In practice, a participant watches a series of video recordings of actual on-road traffic situations and, when having perceived a potential traffic conflict, can click on the relevant road user via a mouse. Faster hazard perception identification is the only driving skill that has a consistent relationship with decreased crash incidences (Horswill, Hill, et al., 2015), thus illustrating the validity of the skill of hazard perception.

Two versions of the HPT (Test 1 and Test 2) were developed for a repeated measures design and to also mitigate practise effects from viewing the same footage twice. The internal consistency of the two HPT versions were adequate with a Cronbach's alpha of .88 and .91 respectively. The two tests each contained 31 hazards (or traffic conflicts), all of which have been validated (Horswill, Falconer, et al., 2015; Wetton et al., 2010). Each test contained 10 hazards appearing in the first 20 mins, 11 hazards appearing in the second 20 mins, and 10 hazards appearing in the last 20 mins of the hour-long tests. Due to the extended length of each driving session (60 minutes), several video clips did not contain any hazards. Clips that did contain hazards could contain one or several hazards. The distribution of video clips that contained hazards, and video clips that did not contain any hazards, was approximately the same across the two different versions of the HPT.

The calculation of participants' mean response times for each condition involved several steps consistent with previous hazard perception data treatment with repeated measures designs (Horswill, Falconer, et al., 2015). The raw response times are determined when a traffic conflict first appears in the video footage until when it is clicked on by the participants. However, each specific traffic conflict varies in its duration and, without standardisation, different types of hazards could apply a greater influence on a condition's mean score. Each raw response time for each specific hazard was converted into a z-score (the raw response time minus the mean raw response times of separate sample divided by the standard deviation of the raw response times of separate sample) which was standardized against the mean raw response times of a separate sample of 58 drivers. Each participant's z-scores were averaged to the clips that they responded to and were then converted back to a mean response time to aid the interpretation of the study results. The separate sample provided raw response times to all 62 hazards in a random order – the clips without hazards were not included in this separate sample as these sessions took approximately 15 minutes to complete and thus, lessened the impact of any time-on-task effect in this separate sample.

This process enabled the examination of time-on-task effects (i.e, Time Period factor) and any interaction with the Sleepiness Level factor.

2.3.2 Visual scanning

Visual scanning behaviour was continuously monitored via the Mirametrix S2 eye tracker. The Mirametrix S2 eye tracker uses a remote infrared eye tracker that does not restrain head movements and employs a 60 Hz sample rate with a 0.5- 1° accuracy. To ensure participants were comfortable throughout the extended duration of the testing session (one hour), a head and chin rest was not utilised. The tracker was located beneath the screen of the computer, which was placed approximately 70cm from the participant. Calibration utilised a 9-point calibration procedure to designated on-screen coordinates. The calibration was considered valid if the maximum spatial error was less than 1 degree, and the average error was less than 0.5 degrees. The obtained eye tracking data was imported into AcqKnowledge software (Bipoac Systems, Goleta, CA, USA) where horizontal, vertical, and fixation duration search variance was calculated and extracted for analysis. Fixations were defined as static eye movements contained within 1.6 degrees of the visual angle for at least 150ms consistent with previous research (Hornof & Halverson, 2002). The indices of standard deviation of horizontal position, standard deviation of vertical position, standard deviation of fixation duration, and fixation count were extracted from the eye tracking data to examine visual scanning behaviour.

2.3.3 Karolinska Sleepiness Scale

The Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990)is a self-report measure of the individual’s current level of subject sleepiness. The KSS is a nine-point Likert scale, with higher scores indicative of higher levels of subjective sleepiness. The KSS is a reliable and valid measure of subjective sleepiness, when compared with objective physiological measures and has been shown to be a sensitive indicator of sleepiness (Åkerstedt et al., 2014).

2.3.4 Psychomotor Vigilance Task

The Psychomotor Vigilance Test (PVT; Wilkinson & Houghton, 1982) is a widely used, reaction-time task measure of behavioural alertness. The PVT requires participants to respond as quickly as possible to a stimulus. Participants fixate on a cross on the computer screen which then disappears after varying interstimulus intervals (1-10 sec) and, in the version of the PVT used in the present study, a red dot appears where the fixation cross was previously. Participants have to respond as quickly as they can to the presentation of the red dot with a press of a spacebar. The reaction time (measured in ms) of each trial appears on screen after the spacebar is pressed (i.e., performance feedback is provided). The standard duration of the PVT is 10-min in length; however, a 5-min version has also demonstrated sensitivity in detecting sleepiness (Loh et al., 2004). The PVT was used in the current study as a supplementary measure of behavioural alertness as it is reliable (Lim & Dinges, 2008) and highly sensitive to both total and partial sleep deprivation (Lim & Dinges, 2008).

2.4 Procedure

The study protocol was approved by the authors' University's Human Research Ethics Committee. The study was advertised to potential participants through the University's student email distribution lists (e.g., undergraduate psychology class lists, research institutes' groups) and the university's research participation webpages. The study protocol required participants to complete three separate study sessions. In the first session, which served as an intake session, participants completed the PSQI and ESS to determine eligibility. Upon meeting participation requirements, a detailed explanation of the study procedure was provided. Once participants signed a consent form, they completed the demographic and traffic-related survey, they were then provided with an actigraph to wear and a simple sleep diary to complete for a duration of two weeks.

Participants returned to the laboratory exactly one week later to complete the first of two, 1.5-hour testing sessions. The study protocol required the manipulation of the participants sleep-wake times. When participants completed the Alert condition, they were required to maintain their habitual sleep duration and with the completion of the Sleepy condition, the participant restricted their habitual sleep duration by two hours by waking up two hours earlier than normal. Participants were instructed to abstain from caffeine or alcohol on each day when testing occurred. They arrived at 08:45 and began the testing by 09:00. Prior to beginning the session, actigraphy data and sleep diary entries were checked to confirm participants maintained the sleep-wake times. Once adherence with the study protocol was confirmed, participants were seated in a comfortable, high-backed chair in preparation for the testing session. Eye tracking calibrations were performed for each individual. Participants then completed the pre-testing PVT. KSS scores were rated prior to beginning the HPT task, and thereafter every 5 minutes via software integrated into the task. After completion of the HPT, participants completed the post-testing PVT. The final testing session was then completed one week following the first testing session, whereby the participants completed the remaining Sleepiness Level condition (alert or sleepy condition).

The participants were tested individually in a laboratory with controlled sound, temperature and light. The level of laboratory ambient light was measured via a Gossen Mavolux light meter (5032B USB, certified to DIN 5032-7 and CIE 69 standards, initial sensitivity of 0.01 1x) and ranged between 382-390 lx. The laboratory temperature was set to 23 degrees. The laboratory contained no time cues – participants’ wristwatches as well as their mobile phones were not available during the testing sessions.

3. Results

3.1 Sleep Restriction Manipulation Check

Duration of sleep (minutes) collected from the actigraphy demonstrated that individuals in the Alert condition (*M* = 500.06, *SD* = 52.68) obtained significantly more sleep than the sleepy condition (*M* = 386.50, *SD* = 51.52), $t(31) = 43.84$, $p < .001$. Adherence to the sleep restriction protocols also entailed comparison of KSS scores prior to starting the study tasks between the Alert and Sleepy conditions. A paired samples t-test demonstrated that individuals reported significantly lower levels of sleepiness in the Alert condition (*M* = 4.19, *SD* = .97) than in the Sleepy condition (*M* = 5.44, *SD* = 1.22), $t(31) = -6.96$, $p < .001$.

3.2 Tests of Hypotheses

Figure 1 displays the mean values for the study variables, with Figure 2 displaying the PVT mean values. As shown in Table 1, a number of significant interaction effects were observed and were followed up with planned comparisons. The tests of hypothesis one, that time-on-task effects will result in impairments of task performance, visual scanning behaviours, and increases in subjective sleepiness were supported. However, this effect manifested more clearly when comparing segments two and three. The tests of hypothesis two, that sleep restriction will result in greater impairments in task performance, visual scanning behaviours, and increases in subjective sleepiness to a greater extent than the alert (non-sleep-restricted condition) was supported. First and foremost, when comparing the Alert condition with the Sleepy condition at each of the three segments, all the Sleepy conditions' values were significantly lower than the Alert condition values. The PVT data (response time and lapses) for the Sleepy condition was significantly slower when compared to the Alert condition pre-and-post the HPT session.

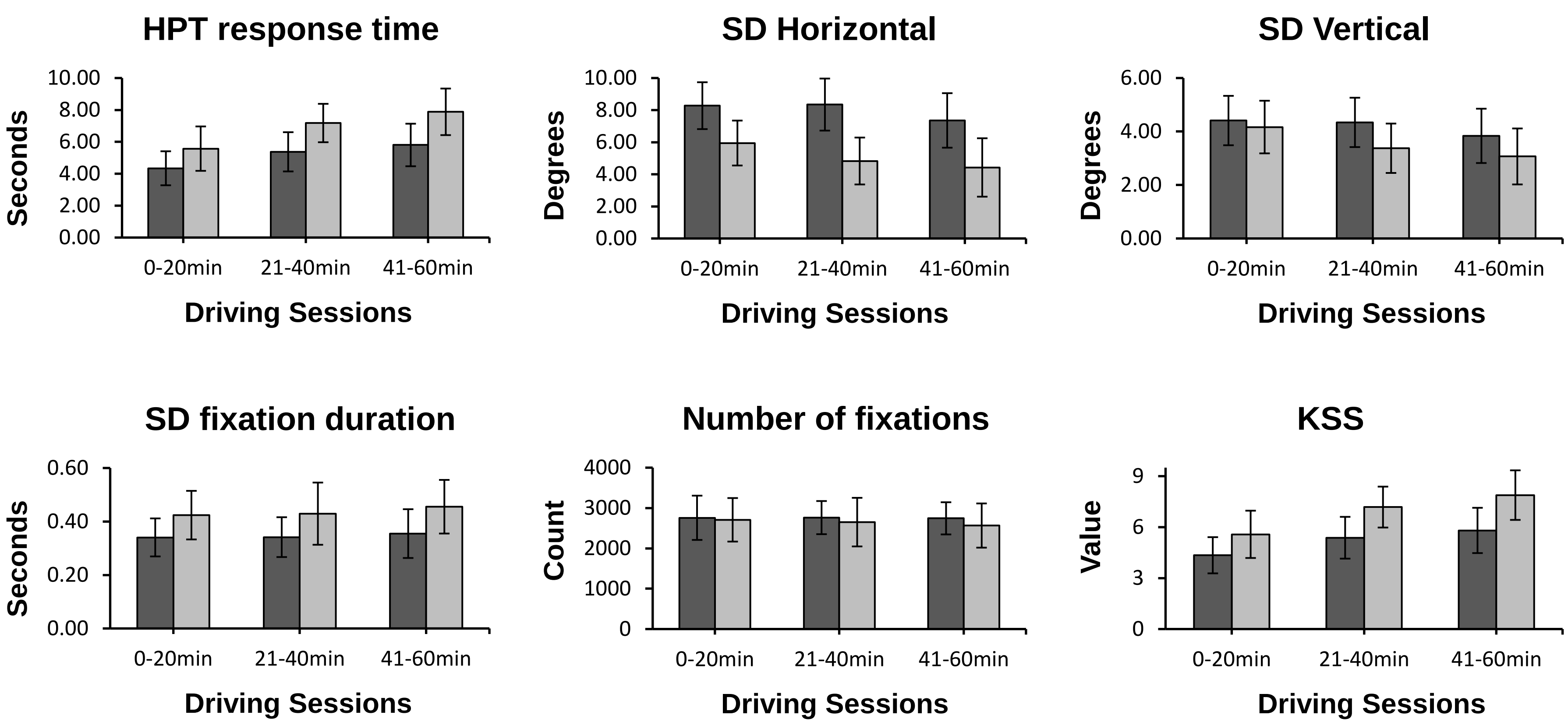

Figure 1. Mean levels of performance, visual scanning, and subjective sleepiness data for the Alert (dark grey) and Sleepy (light grey) conditions. Error bars represent one standard deviation. HPT, hazard perception task; SD, standard deviation; KSS, Karolinska Sleepiness Scale.

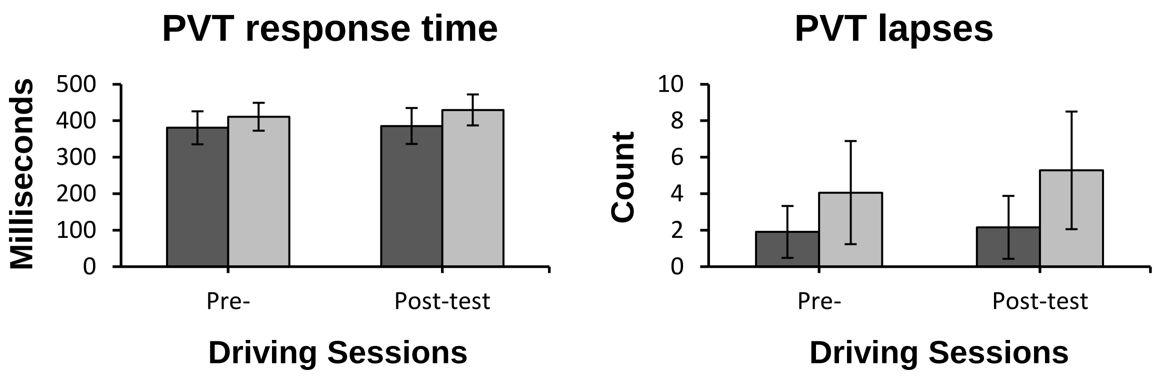

Figure 2. Mean psychomotor vigilance test reaction times and lapses (response time greater than 500 ms) pre- and post-testing.

Table 1. Repeated Measures ANOVA Statistics for the HPT, Visual Scanning, Subjective Sleepiness and PVT Data.

	Sleepy x Time			Planned comparisons						
	F	df	ηp2	S1 vs. S2		S2 vs. S3		S1	S2	S3
Data				Alert	Sleepy	Alert	Sleepy	A vs. S	A vs. S	A vs. S
Hazard Perception Test										
Response time	**4.35***	1.22,37.94	.12	-0.54	**-4.43****	**-7.19****	**-5.34****	**-7.70****	**-9.93****	**-6.62****
Eye tracking										
SD Horizontal Scanning	**6.15****	1.57,48.81	.17	-0.29	**3.69****	**4.93****	**3.24****	**2.34***	**4.24****	**3.44****
SD Vertical Scanning	**16.77****	1.23,38.16	.35	0.26	**3.51****	**5.04****	**3.78****	**1.23**	**7.11****	**4.84****
SD Fixation Duration	**7.13****	2,62	.19	1.84	**-3.07****	**-3.92****	-0.75	**-6.20****	**-7.08****	**-7.19****
Number of fixations	1.96	1.34,41.51	.17	-	-	-	-	-	-	-
Subjective Sleepiness	**7.62****	1.53,47.40	.20	**-7.40****	**-11.48****	**-3.86****	**-6.02****	**-5.37****	**-7.07****	**-6.83****
PVT										
Response time[a]	**6.33***	1,31	.17	-1.26	**-4.74****	-	-	**-4.11****	**-4.35****	-
Lapses[a]	**10.96****	1,31	.26	-0.92	**-10.46****	-	-	**-4.83****	**-5.28****	-

Note. Sleepy = Sleepiness Level factor; Time = Time Period factor; S1 = session one

[a] Note that the PVT data collected at the beginning and end of the Hazard Perception Test, thus a 2 x 2 ANOVA was calculated.

* < .05, ** < .01.

4. Discussion

The current study sought to examine the effect of sleepiness and time-on-task on hazard perception performance, visual scanning behaviours, and subjective sleepiness among a sample of young adult drivers. Participants completed a 60-minute hazard perception task when alert and when sleep-restricted, with the time-on-task effects determined across three distinct 20-minute time segments. All measures utilised in the study were found to be sensitive to the effects of moderate sleepiness. Moreover, participants demonstrated a significant decrease in horizontal and vertical search variances across each segment of time during the sleepy condition. Furthermore, increases in standard deviation of fixation duration were more pronounced in the sleepy condition when compared to the alert condition. Subjective sleepiness and performance of the PVT supported the decline of impairment associated with sleep restriction.

4.1 Main Outcomes

The observed findings demonstrated that a time-on-task effect had occurred with the study variables. The effect was pronounced among the study performance variables of hazard perception response times, the visual scanning variables of SD Horizontal Scanning, SD Vertical Scanning and SD Fixation Duration, the PVT data, and the subjective sleepiness variable. These results are in line with a number of previous studies findings (Loh et al., 2004; Otmani et al., 2005; Shiferaw et al., 2018; Underwood et al., 2011) and will be discussed below.

Hazard perception was the driving performance metric employed in the current study. Several studies have demonstrated how increased driving duration results in poorer driving performance, such as increases in standard deviation of lateral positioning of a vehicle (Åkerstedt et al., 2010), and variability in speed maintenance (Watling et al., 2016). A key focus of the current study was to determine the time-on-task effects with hazard perception.

The results clearly show hazard perception performance decreased over the 60 minutes of task performance for the Sleepy condition. The decrements were slower for the Alert condition as no decreases were observed during the first 40 minutes of the task; however, reaction times decreased towards the end of the 60 minutes. The current study outcomes have implications for extended driving durations, particularly for younger drivers who are more susceptible to the impairments associated with sleepiness than mature adults (Zitting et al., 2018). Consequently, the sleep restriction protocol produced quantifiable impartments in hazard perception performance as well.

A notable finding relates to the eye scanning behaviour observed in the study. The current study sought to examine the difference between visual scanning behaviour, including horizontal and vertical search variance and fixation duration, of sleepy drivers compared to alert drivers. The current study expanded on the existing findings, demonstrating a significant reduction in horizontal and vertical search variances in both conditions, but more so in the Sleepy condition. Additionally, it should also be noted that the largest effect was observed in the vertical search variance. Thus, the current findings are consistent with previous research. For instance, Wang et al. (2017) found a reduced search variance as alertness decreased when driving on actual roads. However, no sleep restriction occurred in Wang et al.’s (2017) study, and the current study’s sleep restriction protocol furthered our understanding of the effects of sleepiness on attention and eye scanning behaviour. This finding is aligned with other research studies that have demonstrated a general reduction in visual scanning behaviours via saccade velocities (e.g., Ahlstrom et al., 2013; Cazzoli et al., 2014; Di Stasi et al., 2015; Schleicher et al., 2008). Although, other research by Shiferaw et al. (2018) noted that when driving on real roads, the range of fixations in the visual field become less ordered and more haphazard when sleep deprived. The differences between the two outcomes could be due to well noted reduced arousal levels that occur in laboratories versus on-road settings.

Nevertheless, the current findings suggest that individuals are less likely to attend to peripheral areas when sleep deprived. This could have serious implications on a driver’s ability to effectively identify and process potential hazards.

The visual breadth of visual scanning behaviour is essential in driving. It allows individuals to attend to stimuli in their periphery where potential hazards are likely to develop. The narrowing of the perceptual range is known to have an attentional component. For instance, increases in attentional workload that occur during dual task studies results in a narrowing of the visual field with perceptual scanning (Crundall et al., 2002). The narrowing of the perceptual range is known to have an attentional component. For instance, increases in attentional workload that occur during dual task studies results in a narrowing of the visual field with perceptual scanning (Crundall et al., 2002; Reimer, 2009) or when driving in demanding road conditions such as fog (Calsavara et al., 2021). Perceptual narrowing has been accepted as an effect during periods of increased workload. In this instance, reductions in search variances occur when drivers report increased workload. At a theoretical level, this effect is likely due to a reduction in cognitive resources available to the driver and results in a change in the range of visual search to limit the sensory information that needs to be processed. In the current study, the restriction in range of visual search is likely due to reduced cognitive resources resulting from the sleep restriction. Increased sleepiness is associated with reduced cognitive resources and poorer cognitive functioning (Nilsson et al., 2005; Smith et al., 2002).

Visual scanning behaviour mediates the role between attention and information acquisition from the driver's environment. Several theorise that eye movements reflect attentional state and changes. The presence of sleepiness limits the availability of attentional resources (e.g., Nilsson et al., 2005; Smith et al., 2002), consequently leading to an impairment in processes. The increase in fixation duration infers participants in the sleepy condition spent a longer duration processing and engaging with stimuli. A limitation from the study's method of averaging scanning variance makes it unclear whether participants were specifically attending to relevant stimuli, for example a potential hazard. Previous research has employed measures of time, first to fixation when encountering stimuli of note, and thus potentially representing a progression of the current results.

No effect was observed with the number of fixations variable. Previous research has found that as driving time increases, decreases in the average fixation rate also occurs (i.e., Lavine et al., 2002; Shiferaw et al., 2018) and thus, the current findings are contrary to the extant literature base. A possible explanation could be due to the variability between individuals in terms of blinking rate, and blinking rate can be modulated based on the attentional task the individual is performing (Unsworth et al., 2019). These findings likely contributed to blink rate having poor sensitivity in detecting increases in sleepiness (e.g., Hasan et al., 2021; Johns et al., 2007).

Strong effects from the study protocol were observed for the subjective sleepiness ratings and the PVT data. Specifically, the Sleepy condition had significantly higher mean KSS scores compared to the Alert condition, and subjective sleepiness was also found to increase across the 60 minutes of driving for both conditions. These outcomes are consistent with several findings (Åkerstedt et al., 2010; Otmani et al., 2005). The findings also highlight the utility of subjective sleepiness experiences in identifying variations in arousal (e.g., Kaida et al., 2006). The PVT outcomes also demonstrate the variation in arousals that occurred in the study. Participants completing the PVT when sleep-restricted experienced increases in response times and the number of lapses, both of which demonstrate increases in behavioural sleepiness (Doran et al., 2001; Lim & Dinges, 2008). No variation in arousal was noted when completing the PVT during the Alert condition, despite increases in the subjective sleepiness scores reported by participants. This is not an uncommon result, such that individuals reporting increased levels of subjective sleepiness have not been connected to reduced task performance (e.g., Van Dongen et al., 2003). The PVT was performed before and after completing the HPT and switching between the HPT and PVT task may have increased arousal levels. That is task-switching is known to increase arousal levels and the participants were likely to have re-orientated their posture for the new task, which is also known to increase arousal levels. These effects may have accounted for the PVT results during the Alert condition. However, the increase in arousal from the task-switching and the potential postural movements may not have been sufficient an effect in the Sleepy condition.

4.2 Practical Implications

The study outcomes have some practical implications for on-road driving. Hazard perception is an important driving skill (Horswill & McKenna, 2004). The current results demonstrate that even fully alert individuals (no sleep impairment) can experience decrements in hazard perception and reductions in even scanning behaviours over a 60-minute period, with sleep-restricted individuals having even greater decrements over the 60 minutes. These outcomes should be considered against the consistent findings of slower hazard perception performance being associated with increased crash likelihood (Horswill & McKenna, 2004; Horswill, Hill, et al., 2015); thus, the current findings have relevance for younger drivers.

Younger individuals are known to be more susceptible to the effects of sleepiness (Zitting et al., 2018) and perceive the risk of driving while sleepy as low. When these findings are combined with the current results, it further adds to the concerns of younger drivers' behaviours. The current study was performed in the morning and, given the performance decrements that can occur in the afternoon with the descending phase of the circadian rhythm (Van Dongen et al., 2003), it is possible the results obtained in the current study could be exacerbated. Overall, these results reinforce the impairments associated with mild sleep deprivation and highlight concerns for road safety.

4.3 Limitations and Future Research

Several limitations of the study need to be considered. The first, relates to the lack of a measure of physiological arousal, such as EEG-defined sleepiness. The current study employed measures of subjective sleepiness (KSS) and behavioural sleepiness (PVT) to gauge variations in arousal. Research has found individual differences in neurobehavioral deficits resulting from sleep deprivation. Thus, interpretation and generalisation should consider that interindividual differences may lead to an overestimation of statistical significance.

Future research might consider examining visual scanning behaviour at the time of response to hazard. Research has suggested that drivers may not need to attend the entire environment and will avert attention only when it becomes necessary to do so (Li et al., 2020). A more direct investigation is essential to determine whether hazards occurring in the visual periphery are more poorly detected when visual scanning behaviour is reduced. The skill of hazard perception has important implications; therefore, an understanding of the correlation between drivers' visual scanning behaviour and hazard perception while sleepy will be critical for road safety.

4.4 Conclusion

Driver sleepiness has severe implications on driving performance and young drivers are more vulnerable to the effects of sleepiness. The purpose of the current study was to examine the effects of sleepiness and time-on-task on hazard perception performance, visual scanning behaviours, and subjective sleepiness, among a sample of young adult drivers. The main outcomes include decrements in hazard perception performance and a restriction in horizontal and vertical eye scanning ranges across the 60-minute session, but with a more pronounced effect when sleep-restricted. These outcomes were consistent with increases in subjective sleepiness and behavioural metrics of sleepiness assessed via the PVT. The current study outcomes provide an important contribution regarding the risks associated with sleepy driving performance.

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