An on-road examination of daytime and evening driving on rural roads: physiological, subjective, eye gaze, and driving performance outcomes

Christopher N. Watling[1,2], Grégoire S. Larue[1,2], Joanne M. Wood[2,3], Alexander Black[2,3]

[1] Queensland University of Technology (QUT), Centre for Accident Research and Road Safety - Queensland (CARRS-Q), Australia

[2] Queensland University of Technology (QUT), Institute of Health and Biomedical Innovation, Australia

[3] Queensland University of Technology (QUT), School of Optometry and Vision Science, Australia

[a] **Corresponding author:** Christopher N. Watling
Centre for Accident Research and Road Safety – Queensland (CARRS-Q)
Queensland University of Technology, 130 Victoria Park Rd, Kelvin Grove, Qld, Aust. 4059
P: +61 7 3138 7747 | **E**: christopher.watling@qut.edu.au

Abstract

Experiencing sleepiness when driving is associated with increased crash risk. An increasing number of studies have examined on-road driver sleepiness; however, these studies typically assess the effect of sleepiness during the late night or early morning hours when sleep pressure is approaching its greatest. An on-road driving study was performed to assess how a range of physiological and sleepiness measures are impacted when driving during the daytime and evening when moderate sleepiness is experienced. In total, 27 participants (14 women and 13 men) completed a driving session in a rural town lasting approximately 60 minutes, while physiological sleepiness (heart rate variability), subjective sleepiness, eye tracking data, vehicle kinematic data and GPS speed data were recorded. Daytime driving sessions began at 12:00 or 14:00, with the evening sessions beginning at 19:30 or 20:30; only a subset of participants ($n = 11$) completing the evening sessions (daytime and evening order counterbalanced). The results suggest reductions in the horizontal and vertical scanning ranges occurred during the initial 40 minutes of driving for both daytime and evening sessions, but with evening sessions reductions in scanning ranges occurred across the entire driving session. Moreover, during evening driving there was an increase in physiological and subjective sleepiness levels. The results demonstrate meaningful increases in sleepiness and reductions in eye scanning when driving during both the daytime and particularly in the evening. Thus, drivers need to remain vigilant when driving during the daytime and the evening.

Keywords: Sleepiness, heart rate, subjective sleepiness, eye tracking, accelerometry, risky driving, naturalistic

1. Introduction

Driving while experiencing sleepiness is a substantial crash risk factor. Case-control studies suggests that up to one-fifth of all fatal and severe crashes are due to the effects of sleepiness (Connor et al., 2002; Tefft, 2018). Moreover, case-control studies demonstrate a dose-response relationship between the increased likelihood of crashes and reduction in time asleep (Tefft, 2018), as well as increases in acute sleepiness while driving (Åkerstedt et al., 2008). While the causes of crashes are multifactorial, it is likely that sleepiness may have contributed to crashes ascribed to other risky driving behaviours (Watling et al., 2013).

The increase in crash risk associated with sleepiness is due to its detrimental effect on several driving skills required for safe driving. In particular, driver sleepiness is associated with increases in lane crossings (Otmani et al., 2005) and variations in lateral positioning (Phipps-Nelson et al., 2011). Increases in lane crossings and variations in lateral positioning occur while driving in simulators (Åkerstedt et al., 2010) and on real roads (Philip et al., 2005) when sleepy. Another driving performance measure sensitive to increases in sleepiness is variations in driving speed (Watling, Åkerstedt, et al., 2016). Moreover, deviation from the posted speed limit (above and below) is also sensitive to increases in sleepiness (Otmani et al., 2005). Variations of the vehicles lateral and longitudinal movements increase when sleepiness of the driver increases and provides a clear indication of decrements in driving performance.

Sleepiness has also been associated with a number of electrophysiological changes involving cortical and cardiac activity as well as eye movements during driving simulator studies. Increases in EEG-defined alpha (8-13 Hz) and theta (4-8 Hz) spectral power density (Otmani et al., 2005) provide clear electrocortical indicators of sleepiness as noted in several driving simulator studies (Åkerstedt et al., 2010; Otmani et al., 2005). However, they can be intrusive to implement with on-road studies. Variations in cardiac activity have been noted to

occur in driving simulator studies when sleepy. The analysis of changes in heart rate over time provides calculations of heart rate variability. Heart rate variability metrics can be derived in the time domain and the frequency domain which have been shown to be sensitive to changes in sleepiness. The measurement of the time between each successive heartbeat is the R-R interval (i.e., inter-beat-interval) and represents the most fundamental measure of cardiac activity and has been used as a consistent measure of arousal level (e.g., Porges & Bohrer, 1990; Tran et al., 2009). Moreover, recording cardiac activity can be less intrusive on the participant.

Physiological changes can also occur with several eye-related movements. A well-documented effect related to eye movements is an increase in blink duration when decreases of arousal occur in simulated and on-road studies (Fors et al., 2018; Watling, Smith, et al., 2016). An important aspect with eye-related movements are associated with the allocation of attention within a driving scene (Crundall et al., 2003). Attentional allocation can be affected by reductions in arousal. Attentional allocations can be measured via time to first fixation as well as fixation duration when a specific road user/s (e.g., vehicle, pedestrian) are the focus of the study. Increases in fixation durations occur when arousal levels decrease (e.g., Cazzoli et al., 2014) however, other studies have found no effect (e.g., Lavine et al., 2002; Shiferaw et al., 2018) or a varied effect (e.g., Schleicher et al., 2008). As such the utility of fixation durations as a sensitive indicator of sleepiness could be lacking. Other research demonstrates fatiguing, extended driving durations can lead to decreases in saccade velocities/eye movements (Ahlstrom et al., 2013; Cazzoli et al., 2014; Schleicher et al., 2008). Moreover, the range of fixations in the visual field become less ordered and more haphazard with increased driving time when sleep deprived (Shiferaw et al., 2018). When visual scanning is restricted, this limits the possibility of identify potential critical driving stimuli from which a

driver can respond in a safe manner (Underwood et al., 2011). These findings can be interpreted as a general decrease in attention and engagement with the visual stimuli.

A limited number of studies have examined on-road driver sleepiness. These on-road studies have provided important information regarding how sleepiness impairs driving performance. Typically, driving performance is assessed during the daytime and during the late night or early morning hours (e.g., 00:15-03:30: (Fors et al., 2018; Sandberg et al., 2011; Wang et al., 2017)). However, during the late night or early morning hours, a driver's sleep pressure from homeostatic and circadian processes is substantial and approaches maximal pressure to initiate sleep (Akerstedt & Folkard, 1995). As such, the utility of these studies is limited to these hours. While crash risk is elevated during late night and early morning driving times (Åkerstedt & Kecklund, 2001; Pack et al., 1995), it is also important to understand sleepiness impairment during times of more moderate sleepiness that are typical of night-time driving, such as the early evening.

Current evidence suggests that moderate sleepiness impairs driving ability and safety. For instance, Åkerstedt et al. (2008) in their biomathematical modelling of sleepiness from on-road crash data illustrates a near exponential increase in crash risk with increases in subjective sleepiness value, with values higher than 3 on the 9-point Karolinska Sleepiness Scale (KSS: Åkerstedt & Gillberg, 1990) associated with an increase in the odds of having a sleep-related crash (Åkerstedt et al., 2008). Normative data of the diurnal variations in subjective sleepiness suggests moderate levels of sleepiness (KSS value of approximately 5: verbal anchor "neither alert nor sleepy") are experienced after approximately 19:00 (Akerstedt et al., 2017). As such, examining drivers on real roads during the evening when moderate sleepiness is experienced, is an important area to explore given the lack of on-road studies.

The current study assessed the effects of driving on real roads during the daytime and evening (when moderate sleepiness is experienced) on physiological and subjective sleepiness measures and driving performance. Overall, two research questions were posed: i) what effect does a one hour on-road driving session have on drivers' physiological sleepiness, subjective sleepiness and levels of driving performance during the day and evening; and ii) what are the differences between driving during the day and evening on driver's physiological sleepiness, subjective sleepiness and driving performance.

2. Method

2.1 Participants

Participants included 27 healthy, visually normal adults (14 women and 13 men) with a mean age of 43.35 years ($SD = 12.91$). All participants were licensed drivers who reported having had their licence for on average 23.96 years ($SD = 13.98$) and drove on average 133 km/week ($SD = 95.73$). Overall, participants reported an average habitual sleep duration of 8.40 hr ($SD = 1.06$) as assessed via the Sleep Timing Questionnaire (Monk et al., 2003). Specific exclusion criteria required that all participants met the visual requirements (with or without corrective lens) for a private driving licence and completed a vision screening assessment to ensure that they met these minimum visual requirements (see Table 1). Each participant received a monetary compensation of 120 NZD for each driving session they completed.

Table 1. Participants' visual acuity and contrast sensitivity.

	Mean (*SD*)	Range	Licencing cut offs
Visual Acuity Better-eye (logMAR)[#]	-0.03 (0.09)	-0.20 - 0.20	-
Visual Acuity Worse-eye (logMAR)[#]	0.02 (0.09)	-0.12 - 0.20	-
Visual Acuity Both eyes (logMAR)	-0.07 (0.08)	-0.22 - 0.18	0.30
Contrast Sensitivity (logCS)[*]	1.96 (0.12)	1.65 – 2.25	-

[#] Visual acuity with both eyes is a requirement for licensing rather than in either eye seperately

*Contrast Sensitivity is not used as a specific criteria for licencing.

2.2 Measures

2.2.1   Driving Environment and Test vehicle

The study was undertaken in the rural town of Marton (population 4950), located on New Zealand's North Island (Statistics New Zealand, 2018). The driving route was approximately 55 km in length and took approximately one hour to complete. The route started in the town of Marton, with, the majority of driving taking place on open rural roads. The driving route included roads that had a range of speed limits (100km/hr: 74.64%; 80km/hr: 4.83%; 70km/hr: 3.98%; and 50km/hr: 16.55%) as well as a limited number of roundabouts, stop and give way intersections, and railway crossings. The same driving route was used for both daytime and night-time conditions. In the event of inclement weather, the driving session was cancelled and rescheduled. The test vehicle was a 2007 Hyundai Accent, automatic, dual controlled car. A qualified driving instructor was seated in the front passenger seat and two researchers were seated in the rear passenger seats.

2.2.2   Sleep Timing Questionnaire

The Sleep Timing Questionnaire (STQ; Monk et al., 2003) is a self-reported questionnaire that assesses habitual sleep and wake times. Measures of an individual's habitual bedtime (good night time, GNT) and habitual wake-time (good morning time, GMT) were derived for weekdays and weekends. The participants' habitual sleep duration was obtained by subtracting GNT from the GMT data. The reliability of the STQ has been demonstrated with good test-retest correlations (GNT: $r = .71$; GMT: $r = .83$) and the validity of the STQ is acceptable, with moderate correlations (GNT: $r = .59$; GMT: $r = .77$) between the STQ and sleep-wake data collected using actigraphic methods (Monk et al., 2003).

2.2.3   Heart Rate Variability

The participants' physiological sleepiness was monitored via heart rate variability. A Polar H7 chest strap (Polar Electro Oy, Kempele, Finland) was used to record the R-R interval (i.e., inter-beat-interval), which is measured in milliseconds between each successive heartbeat. The Polar H7 chest strap records data at a frequency of 1000 Hz and is placed centrally on the participant's chest at the bottom of the sternum. Increases in the duration of the R-R interval is indicative of greater physiological sleepiness (Tran et al., 2009).

2.2.4   Karolinska Sleepiness Scale

The Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990) is a self-reported measure of the individual's current level of subject sleepiness, involving 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 (Kaida et al., 2006).

2.2.5   Eye tracker

The participants' eye movements were recorded via an Applied Science Laboratories Mobile Eye-XG eye tracker. The Mobile Eye-XG comprises a lightweight frame that does not restrict head movements and incorporates a forward-facing scene camera and eye camera that captures the corneal reflection and pupil position of the right eye. The eye tracking data is sampled at 30 Hz and has a tracking accuracy of 0.5 to 1.0° (Applied Science Laboratories, 2014). The two indices of standard deviation of horizontal and vertical eye position were extracted from the eye tracking data to examine the extent of the visual scanning patterns. To determine the extent of the general decrease in attention and engagement with scanning the visual scene during an extended driving situation, standard deviation of horizontal and vertical eye position were the preferred measures.

2.2.6   Driving performance measures

Measures of driving performance included vehicle kinematic data and GPS speed data. The vehicle kinematic data was recorded from a three-axial accelerometer fitted to the test vehicle (3-Space Sensor Data Logging 2.0, YOST labs Inc., Portsmouth, Ohio, USA). The 3-Space Sensor Data Logger employs an on-board quaternion-based Kalman filtering algorithm to determine orientation relative to an absolute reference in real-time, with the data sampled at 20 Hz.

Risky driving g-force events were extracted from the accelerometry data based on the thresholds established by Simons-Morton, Ouimet, Zhang, Klauer, Lee, Wang, Albert, et al. (2011) of longitudinal acceleration ($\geq$ 0.35 g), longitudinal deceleration ($\leq$ -0.45 g), lateral negative (left) turn ($\leq$ -0.50 g), lateral positive (right) turn ($\geq$ 0.50 g). Risky driving composite scales were created for the longitudinal data that included the summation of the acceleration and deceleration counts and for the lateral data including the summation of the negative and positive turns. Global Positioning System speed data was measured via a Samsung S4 smartphone (Samsung Group, Seoul, South Korea) fitted to the test vehicle with the data sampled at 1 Hz. Risky driving and speeding events were extracted from the GPS speed data as variations (standard deviation) from the posted speed limit (above and below). Deviation from the posted speed limit (above and below) is a sensitive indicator of sleepiness when driving (Otmani et al., 2005).

2.3 Procedure

The study's protocol received ethical approval from the University Human Research Ethics Committee and Health and Safety approval. The initial testing session included assessment of visual function using standard visual acuity and contrast sensitivity charts, trying on the eye tracking equipment, completing a demographic survey, and signing the consent form. The second session involved driving under daytime conditions and a subset of

participants (n = 11) were recruited to complete an evening testing session. Daytime sessions began at 12:00 or 14:00, with the evening sessions beginning at 19:30 or 20:30 in order to adjust for the increasing duration of daylight in New Zealand during summertime. The order of completing the daytime or evening driving sessions were counterbalanced. No participant completed the two driving tasks on the same day but were completed on different days of the week – to mitigate potential fatigue effects form driving on the same day. Participants were instructed to maintain their usual sleep habits the night prior to the driving session and to refrain from consuming alcohol the day before and on the day of the driving session.

At the beginning of each driving session, the eye tracking glasses were fitted and calibrated using a five-point calibration procedure. Participants were instructed to drive as they would normally, to observe posted speed limits and that they would be responsible for all traffic infringements incurred during the driving session. The participant's subjective sleepiness was assessed immediately prior to commencing the drive via the KSS. The driving route included some intersections and before each intersection, the participant was instructed which direction to take 500 meters in advance of the intersection from one of the two researchers seated in the rear of the car, while the other researcher was responsible for the operation of the recording equipment. At the completion of the driving session, each participant's subjective sleepiness was reassessed, and they completed a post-drive survey after their last driving session.

2.4 Statistical Analysis

To address research question one, the effects of a one hour on-road driving during the day and evening, a series of one-way repeated measures ANOVAs were conducted using the daytime and evening driving data. The within-groups factor of Driving Segment had three levels, being the first, second, and third section of the drive. Each driving session had a slightly different duration (M = 55.48; SD = 4.38; range = 48.95-66.50 minutes) and so the

three Driving Segment levels were three equal sections of the total driving time. The three sections had an average duration of 18.49 minutes. These divisions were based on previous work as changes in arousal levels can occur after 20 minutes of driving (Watling, 2016; Watling, Åkerstedt, et al., 2016) with increases in sleepiness and greater decrements in performance the longer the duration of driving. As such, planned comparisons (paired t-tests) compared Section 1 with Section 2 (comparison 1) and Section 2 with Section 3 (comparison 2). Research question two, sought to determine the differences between during the day and evening driving and involved performing a series of 2 x 3 repeated measures ANOVAs and as the KSS was obtained pre- and post-driving, a 2 x 2 repeated measures ANOVAs was performed. The within-groups factors were Time of Driving (daytime and evening driving) and Driving Segment (first, second, and third section of the drive) which was (pre- and post-driving) for the KSS data. Planned comparisons (paired t-tests) were performed that compared the daytime and evening driving data at Sections 1, 2, and 3 or pre- and post-driving. The Greenhouse-Geisser correction was reported if the Sphericity assumption was breached.

There were some missing data for the daytime driving sessions. Subjective sleepiness data was missing for one participant ($n = 26$); for the eye tracking data, five participants had more than 20% missing data and were excluded from the analysis, thus the main analysis comprised $n = 22$. This was a conservative approach as previous eye tracking studied have excluded eye tracking data if the missing value exceeded more than 50% of the data (Lee et al., 2016; Nuske et al., 2014). On average 10.59% ($SD = 3.85$, Range = 5.16-17.31) of the participants eye tracking data was missing/excluded. Eye tracking artefact and poor data quality was managed via two sources, software-based and manual screening by a research assistant to ensure data quality. Complete vehicle kinematic data were obtained for $n = 24$ during the daytime sessions and $n = 11$ for the evening sessions.

3. Results

Table 2 displays the means, standard deviations, ANOVA statistics, and planned comparisons related to research question one regarding the effect of one hour of driving under in-traffic conditions. Regarding the daytime analyses, five significant main effects were found for the eye gaze data and risky driving variables of speed, longitudinal metrics, and lateral metrics. Planned comparisons on the eye tracking data revealed a significant decrease in scanning extent between Section 1 and 2 for both horizontal and vertical eye movements. The Risky driving – SD speed variable increased significantly across all three sections. However, the Risky driving longitudinal and lateral metrics demonstrated a mixed pattern of results. The longitudinal metrics demonstrating an increase and then a decrease in the number of counts between section 1 and 2 and section 2 and 3 respectively, whereas the lateral metric demonstrated a decrease only between Section 1 and 2.

Significant main effects were found for all of the evening driving analyses. The HRV R-R index and KSS scores increasing significantly over the entire driving session, indicating increases in both physiological and subjective sleepiness. The eye gaze data for both the horizontal and vertical variables demonstrated a significant decrease in scanning over the entire driving session. The risky driving measures of longitudinal metrics and SD of speed increased between Section 1 and 2 with no significant change between Section 2 and 3.

Table 2. Descriptive Statistics and One-way within subjects ANOVAs Summary for Driving Segment Simple Effects and Planned Comparisons for Daytime and Evening Driving Sessions.

Measure	Mean (SD)			ANOVA summary				Planned comparisons	
	Section 1	Section 2	Section 3	F	df	η^2	power	S1 vs. S2	S2 vs. S3
Daytime									
HRV R-R index	737.33 (124.73)	748.57 (132.71)	748.84 (132.29)	3.03	1.24, 32.21	.10	.44	-	-
KSS[a]	2.46 (1.01)	-	2.56 (1.32)	0.29	1, 25	.01	.08	-	-
Eye gaze SD HorPos[b]	24.50 (7.59)	21.36 (5.20)	21.77 (4.87)	**5.17***	1.20, 25.24	.20	.64	**2.68***	-0.84
Eye gaze SD VertPos[b]	18.62 (6.05)	15.42 (5.60)	14.52 (5.39)	**15.48****	1.28, 26.80	.42	.98	**4.43****	1.78
Risky driving – longitudinal metrics[c]	102.75 (58.46)	163.21 (82.37)	101.50 (46.07)	**10.83****	1.56, 35.83	.32	.96	**-3.40****	**3.81****
Risky driving – lateral metrics[c]	32.67 (13.96)	14.71 (11.86)	18.92 (9.00)	**31.78****	2, 46	.58	1.00	**6.71****	-2.01
Risky driving – SD speed	20.47 (1.89)	22.02 (1.38)	23.48 (2.09)	**32.41****	2, 52	.56	1.00	**-3.91****	**-4.67****
Evening									
HRV R-R index	748.73 (112.83)	763.09 (113.88)	778.39 (114.79)	**19.68****	1.30,12.96	.66	1.00	**-2.72***	**-6.17****
KSS[a]	2.69 (0.81)	-	4.00 (0.89)	**19.84****	1, 10	.67	.98	**-4.45****	-
Eye gaze SD HorPos[d]	21.31 (3.25)	18.16 (3.28)	16.63 (2.82)	**4.60***	1.36, 35.33	.15	.76	**5.75****	**2.78***
Eye gaze SD VertPos[d]	17.46 (2.68)	15.96 (2.18)	14.20 (1.67)	**13.94****	1.23, 31.90	.35	.97	**4.77****	**2.35***
Risky driving – longitudinal metrics[d]	44.45 (22.27)	70.55 (33.58)	59.00 (28.05)	**6.70****	2, 20	.40	.87	**-3.39****	1.49
Risky driving – lateral metrics[d]	23.91 (14.37)	11.91 (3.91)	16.45 (12.66)	**6.81***	1.30, 13.03	.41	.74	**2.79***	-1.59
Risky driving – SD speed	20.57 (1.49)	22.15 (0.91)	22.93 (1.95)	**12.66****	2, 20	.56	.99	**-4.30****	-1.47

*$p < .05$, **$p < .01$.
[a] KSS scores were only collected pre- and post-drive – these values are listed in sections 1 and 3, $n = 26$; [b] $n = 22$; [c] $n = 24$; [d] $n = 11$.
Note: SD = Standard Deviation; S1 = Section 1; S2 = Section 2; S3 = Section 3; HorPos = Horizontal Positioning; VertPos = Vertical Positioning.

Table 3 displays the means, standard deviations, ANOVA statistics for the Driving Segment and Time of Driving interaction, and planned comparisons performed to evaluate research question two. Significant effects were found for HRV R-R index, KSS, Eye gaze SD Horizontal Position, Risky driving – longitudinal metrics, and Risky driving – lateral metrics. Planned comparisons revealed that HRV R-R index was larger during Section 2 and 3 for the evening driving, indicating greater sleepiness. However, the KSS comparison at the completion of the drive was approaching significance ($p = .052$). The comparisons of the eye gaze data revealed during Section 2 and 3 that the SD of Horizontal Position was smaller during evening driving. A number of significant comparisons were observed with the risky driving longitudinal and lateral metrics, with the daytime values significantly greater than the evening values.

Table 3 ANOVA summary for Time of Driving X Driving Segment Interaction and Planned Comparisons between Daytime and Evening Driving Sessions.

Measure	ANOVA summary				Daytime vs evening planned comparisons		
	F	df	η^2	power	S1	S2	S3
HRV R-R index	**3.83**[*]	2, 20	.28	.36	-1.74	**-2.37**[*]	**-3.16**[**]
KSS[a]	**8.60**[*]	1, 10	.46	.75	-0.66	-	-2.21[†]
Eye gaze SD HorPos	**3.58**[*]	2, 20	.26	.60	1.54	**2.97**[*]	**5.19**[**]
Eye gaze SD VertPos	2.95	1.14, 11.37	.06	.12	-	-	-
Risky driving – longitudinal metrics[b]	**3.78**[*]	2, 18	.30	.61	**3.23**[**]	**4.21**[**]	**2.49**[*]
Risky driving – lateral metrics[b]	**3.60**[*]	2, 18	.29	.59	**2.70**[*]	0.80	1.03
Risky driving – SD speed	1.76	2, 20	.15	.32	-	-	-

[*] $p < .05$, [**] $p < .01$, [†] $p = .052$.
[a] KSS scores were only collected pre- and post-drive – these values are listed in sections 1 and 3; [b] $n = 10$.
Note: S1 = Section 1; S2 = Section 2; S3 = Section 3; HorPos = Horizontal Positioning; VertPos = Vertical Positioning.

4. Discussion

The main finding demonstrated differences between daytime and evening driving in terms of decrements in horizontal and vertical scanning range, especially during the evening driving sessions. During the daytime session a reduction in the extent of horizontal and

vertical scanning paths occurred during the second driving section. Similar patterns of decrements in the evening driving sessions were also observed but the reductions continued until the end of the driving session. Differences were also demonstrated between the daytime and evening sessions in terms of greater levels of physiological sleepiness, a narrowing of horizontal scanning, and unexpectedly, a reduction in the magnitude of risky driving during the evening driving.

Research question one was concerned with the effect of a one hour on-road driving session on drivers' physiological and subjective sleepiness as well as driving performance during the day and evening. No increase in physiological or subjective sleepiness were observed during the daytime driving session, however, there was a narrowing of horizontal and vertical scanning across session 1 to session 2. The current results are consistent with previous research, whereby increases in driving duration leads to a narrowing of scanning range (Mills et al., 2001). Driving performance was poorer from section 1 to section 2 with increases in Risky driving – longitudinal metrics and standard deviation of vehicle speed continued to increase across the entire duration of the daytime driving session and thus some decrement of driving performance occurred throughout the session. These decrements in scanning range and driving performance can be interpreted as a time-on-task effect (e.g., Zeller et al., 2020). However, it is also possible that differences in driving metrics could also be impacted by the natural variations in the type of driving environment, such as sections of monotonous driving settings (Larue et al., 2011) or variations in road geometry (Farahmand & Boroujerdian, 2018) which can impact on arousal levels.

The trends in the evening driving session revealed an increase in sleepiness, both physiological and subjective as well as a narrowing of horizontal and vertical scanning across the entire driving session, in contrast to the daytime sessions. There was poorer vehicle control from section 1 to section 2 with an increase in the longitudinal metric and an increase

in the standard deviation of speed. These findings suggest that meaningful increases in sleepiness as well as a narrowing of the search patterns can occur during the evening and could have safety implications. Specifically, increases in physiological and subjective sleepiness are associated with simulated driving incidents such as driving outside of their designated lane (Watling, Åkerstedt, et al., 2016) or simulated crashes (Williamson et al., 2014). Reductions in visual scanning ranges can also limit the identification of hazards in the road ahead (Crundall et al., 2003; Underwood et al., 2011), with faster hazard perception associated with decreased crash likelihood (Horswill et al., 2015).

The second research question sought to determine the differences between driving during the day and evening on driver's physiological and subjective sleepiness as well as driving performance. A number of meaningful differences were observed in the data, including significant increases in physiological sleepiness during the evening sessions as well as increases in subjective sleepiness that was approaching significance (representing a large effect size, see Table 3) at the end of driving session. Importantly, the eye gaze behaviour horizontal scanning was reduced during the evening compared to the daytime driving sessions 2 and 3. Previous night-time driving studies demonstrate increases in sleepiness and impaired driving performance occurring during the night-time or early morning (Fors et al., 2018; Sandberg et al., 2011). The current findings however, also demonstrate night-time driving can also result in increased physiological sleepiness and a narrowing of the horizontal eye scanning range.

The possible explanations for the narrowing of horizontal scanning range could be due to a restriction in the extent of visual information at night especially in the periphery (e.g., Konstantopoulos et al., 2010). However, this restriction of visual information at night cannot account for the decreased scanning range decreased across the three sections and the effect size was also greater in the evening session than the daytime sessions. However, an

alternate explanation or a modifying factor could be due to the increased workload of the driver. Research by Mills et al. (2001) has shown increases in duration of driving leads to a narrowing of scanning range, but importantly this narrowing coincides with an increase in mental workload and applying extra effort to the task of driving. Previous studies have shown increases in mental workload also co-occurs with increases in sleepiness (Verwey & Zaidel, 1999) and as such it is likely that increases in sleepiness levels is associated with narrowing of scanning range and the an increase in mental workload could also be contributing.

The differences in risky driving metrics between driving during the day and evening could also be due to reduced illuminance levels. For instance Owens et al. (2007) found reduced illumination levels for drivers was associated with reduction in mean vehicle speeds. In contrast, other findings suggest mean driving speeds do not differ significantly between day and night (Jägerbrand & Sjöbergh, 2016). Moreover, numerous studies have shown lateral metrics and lane deviations increase when driving during the night (Fors et al., 2018; Hallvig et al., 2013) which contrasts the current results where drivers were more cautious during the evening driving session. The cautious driving style during the evening may be due to demand characteristics where the participants were driving a research vehicle with had three passengers, being the researchers. This situation may have induced a rather conservative driving style in the study participants.

The findings from the present study need to be considered in relation to the limitations of the study. The number of participants that completed the evening drive was limited to 11 participants. Another limitation was the limited number of assessments (i.e., pre- and post-driving) of subjective sleepiness. It is possible variations in sleepiness could have occurred during the driving sessions but were not measured. Another limitation relates to the presence of the driving instructor and researchers in the test vehicle. It has been shown in simulated (Ouimet et al., 2013) and on-road studies (Simons-Morton, Ouimet, Zhang, Klauer, Lee,

Wang, Chen, et al., 2011) that the presence of a passenger who does not encourage risk taking by the driver, leads to fewer risky driving behaviours than when driving solo. Finally, variations in driving environment, road geometry and visual scene (Larue et al., 2011) could have resulted in differential levels of arousal and eye gaze behaviours. Future research could seek to improve upon these limitations of the current study.

In conclusion, the current study sought to examine the effects of driving on real roads during the daytime and during the evening when moderate sleepiness is experienced. Overall, there were reductions in the horizontal and vertical scanning ranges during the initial 40 minutes of driving and some variations in the risky driving indices. During the evening driving there was an increase in physiological and subjective sleepiness, as well as a narrowing of horizontal and vertical eye scanning across the one hour. Differences between the daytime and evening sessions were also found with a general increase in sleepiness during evening driving and smaller scanning horizontal scanning ranges. The results suggest meaningful effects in terms of increases in sleepiness and reductions in eye scanning can occur when driving during the evening.

5. Acknowledgements

6. Author Contributions

Christopher N. Watling: Conceptualization, Methodology, Data Curation, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Visualization; Grégoire S. Larue: Conceptualization, Methodology, Investigation, Data Curation, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Visualization; Joanne M. Wood: Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing;

Alexander Black: Conceptualization, Methodology, Writing - Original Draft, Writing -

Review & Editing

7. Open Practices Statement

None of the data or materials for the experiments reported here is available, and none of the

experiments was preregistered.

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