Abstract

Almost half of Canadian healthcare workers are employed in rotating day/night shifts to provide essential 24-hour services. However, poor sleep quantity and quality are pervasive in shiftwork and may negatively impact cognitive functions required for driving. Furthermore, healthcare shiftworkers (HCSW) are under-represented in research examining shiftworkers' sleep and driving performance. Thus, this dissertation examined sleep, sleepiness and driving performance in HCSW via three aims. First, chapter 2 aimed to quantify and describe HCSWs' sleep-related driving experiences and advance the understanding of occupational adaptations used by HCSWs to meet driving demands. Second, chapter 3 aimed to quantify differences in sleep, sleepiness, and driving performance outcomes between HCSW and dayworkers (DW). Finally, chapter 4 aimed to identify whether demographic, sleep- or driving-related outcomes may predict the 6-week sum of adverse driving events reported.

Chapter 2 findings show that the majority of HCSWs experienced insufficient sleep during their workweek and reported elevated rates of risky and sleep-related driving behaviours. Despite recurring, multi-layered adaptations to mitigate the risk of sleep-related driving events, 90% of HCSW reported at least one sleep-related driving event in the past year, described as a routine and predictable consequence of shiftwork. Limited training, resources, and unpredictable scheduling were highlighted as systemic barriers disproportionately affecting younger HCSW. Chapter 3 findings show that HCSW (versus DW) experience significantly lower sleep quantity and quantity, and more frequent occurrences of severely insufficient sleep below thresholds indicated for impaired driving. Further, HCSW reported higher ratings of subjective sleepiness and higher occurrences of sleep-related and adverse driving events. Chapter 4 findings identified shiftwork, younger age, poorer sleep quality in the past month, and more frequent occurrences of insufficient sleep <6h/24h as factors significantly predicting a higher 6-week sum of adverse driving events. Overall, findings suggest that HCSW are an at-risk group of drivers, with important implications in future research, healthcare worker education, and policy, with a crucial need to focus on younger workers.

Keywords

Shiftwork; Driving Performance; Sleep; Healthcare; Mixed-Methods.

Summary for Lay Audience

In Canada, almost half of healthcare employees work rotating day/night shifts providing 24-hour care. However, shiftworkers commonly report short or low-quality sleep, which can impact mental abilities needed for driving. Unfortunately, healthcare shiftworkers (HCSW) have not been included in research on shiftwork and driving outcomes. Therefore, the goal of this dissertation is to examine HCSW sleep, sleepiness, and driving outcomes with three goals. Chapter 2 examines HCSWs' self-reported sleep, sleep-related driving events (e.g., sleepiness), or negative driving events on-road (e.g., leaving lane), and describes HCSWs' sleep-related driving experiences and coping strategies. Chapter 3 examines whether HCSW (versus day workers, DW) differed in sleep, sleepiness, and driving outcomes. Chapter 4 examines what factors (e.g., about the person, their sleep or driving outcomes) might identify how many negative driving outcomes they report over 6 weeks. Chapter 2 shows that 65% of HCSWs reported short sleep at least weekly and reported more often engaging in risky or sleepy driving behaviours. Despite using multiple strategies to reduce sleepy driving experiences, 90% reported severe sleepiness while driving in the past year, and suggested this was a regular, predictable result of shiftwork. Barriers primarily impacted younger workers, such as little training or support and unpredictable schedules. Chapter 3 shows that HCSW had shorter and lower quality sleep overall, and more often had very short sleep below levels considered to cause impaired driving. Healthcare SW also reported a higher level of sleepiness while driving and a higher number and type of negative driving events than DW. Chapter 4 shows that factors including shiftwork, younger age, poorer quality sleep and more often having very short sleep predicted the highest number of negative driving events over a 6-week period. Overall, these findings show HCSW are an at-risk group of drivers due to poor sleep quantity, decreased sleep quantity, increased sleepiness, and higher number and type of negative driving events. These findings will inform healthcare worker education, workplace policy, and future research.

Co-Authorship Statement

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Ms. Knott completed the conceptualization, design, research proposal, ethics, all participant recruitment, study administration, data collection, data analysis, interpretation, data display, manuscript writing, and research presentations. Ms. Knott mentored, trained, and oversaw all research volunteers and validated data from delegated tasks.

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Mr. Cheung and Mr. Kim assisted with i-SHIFT 2 Study Qualtrics survey technical implementation, sleep data interpretation, data scoring and entry. Mr. Cheung and Mr. Kim will be co-authors on manuscripts from Chapters 3 and 4.

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List of Abbreviations

DBQ	Driving Behaviour Questionnaire
DW	Day worker
ESS	Epworth Sleepiness Scale
FTDS	Fitness-to-Drive Screening Measure
h/24h	hours per 24-hour period
HADS	Hospital Anxiety and Depression Scale
HCSW	Healthcare shiftworker
KSS	Karolinska Sleepiness Scale
MVC	Motor vehicle collision
O-SDMT	Symbol Digit Modalities Test, oral version
OTMT-A	Trail Making Test – A, oral version
OTMT-B	Trail Making Test – B, oral version
PSQI	Pittsburg Sleep Quality Index
rMEQ	Revised Morningness Eveningness Questionnaire
SE	Sleep Efficiency
SFDB	Scale of Fatigued Driving Behaviour
SW	Shiftworker
TIB	Time In Bed
TST	Total Sleep Time

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Preface: A COVID-19 Impact Statement

The COVID-19 pandemic has left an indelible mark on this doctoral thesis research. In January 2020, this research was originally proposed as an in-person driving simulator study (one session) and interview in the i-Mobile Driving Research Lab at Western University. Recruitment was expected to take place from healthcare workers in the London-Middlesex area. However, because of the public health mandates and lockdowns instituted to manage the pandemic across Ontario and Canada, the traditional in-person methods used to examine driving performance were rendered impossible for an unknown period of time. It soon became obvious that the sustained nature of the pandemic would require both creativity and innovation to achieve the goal of studying sleep and driving performance in healthcare workers and would require the use of online and/or remote methods of data collection.

The impacts of these methodological choices are evident throughout the study design, data collection procedures, and participant recruitment. Changes in study design yielded two distinct studies. First, a mixed-methods study comprised of an online survey and interview conducted during the first year of the pandemic from October 2020 through April 2021. During this time, the second study quantifying sleep and driving performance between healthcare shiftworkers and dayworkers re-designed. This study thus used daily driving logs to track driving events in participants' naturalistic driving environments (instead observing simulated driving skills) and used cognitive screening tools validated for telephone administration. Remote data collection and limits to in-person participant interactions also included couriering materials to participants' homes thus enabling participant recruitment to expand across all Southwestern Ontario. Data collection for the second study occurred from May 2021 through February 2022.

Beyond the impacts on methodological choices, the COVID-19 pandemic also had direct and significant impacts on healthcare worker participants for both studies. Most notably, while healthcare workers experienced the same restrictions and impacts as the general public, they also coped with increased risk of exposures and illness at work, more complex workloads and overtime demands, increasing rates of stress and burnout, eventually culminating in documented “catastrophic levels”[1] of staff shortages and attrition, delayed access to care, unit closures, and ambulance shortages[2] across Ontario. I am forever grateful for healthcare workers who, despite their own demands, saw the value of this research and found the time to participate.

Given the worsening staff shortages and working conditions through the pandemic, and thus the data collection period for this research, I anticipate that the effects noted in this dissertation data may have intensified and warrant further investigation.

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[1] Hassan, Y. (2022, June 18). Healthcare workers call for government help as burnout worsens and staff shortages increase. CBC News. URL https://www.cbc.ca/news/politics/healthcare-workers-burnout-1.6492889

[2] Porter, K. (2022, January 26). Union survey finds paramedics facing high stress with little support. CBC News. URL: https://www.cbc.ca/news/canada/ottawa/cupe-503-survey-paramedics-morale-stress-understaffed-1.6326671.

1 Introduction

Shiftwork presents myriad risks to employee health including increased chronic health complaints, workplace injuries, and motor vehicle collisions, making it *"one of the biggest occupational problems of the modern world"* (Kantermann et al., 2010, p. 98). Notably, shiftwork is shown to contribute to insufficient sleep (<6.5h/24h) and sleepiness, which can impair the neurobehavioural and neurocognitive functions necessary for driving (Akerstedt, 2003; Barco et al., 2012; Bixler, 2009; Kecklund & Axelsson, 2016). Furthermore, a systematic review found that overnight shiftwork and subjective sleepiness were *likely* and *possible* predictors of adverse driving outcomes, respectively (Knott et al., 2020). However, insufficient evidence was found on the impact of 12h rotating day/night shifts which is commonly required in healthcare settings (Knott et al., 2020). Moreover, healthcare worker populations other than physicians were under-represented in research studies (e.g., nurses, paramedics) (Knott et al., 2020). In Canada, while 28% of all employees work shiftwork, 45% of all healthcare workers, and up to 80% of paramedics are employed in shiftwork (Fischer & MacPhee, 2017; Williams, 2008). Therefore, this dissertation focuses on the effects of shiftwork on sleep, sleepiness, and driving performance in non-physician healthcare shiftworkers. The following literature review (Chapter 1) provides an overview of the impact of shiftwork on sleep (section 1.1); the impact of sleep and sleepiness on function (section 1.2); relevant driving behaviour models to conceptualize how deficits arising from insufficient sleep and sleepiness may negatively impact driving performance (section 1.3); insufficient sleep and fitness to drive (section 1.4); and driving performance indicators in shiftworkers (section 1.5). The literature review concludes with a rationale for this dissertation (section 1.6) and the purpose and structure of the dissertation research (section 1.7).

1.1 The Impact of Shiftwork on Sleep

In Canada, adults (i.e., 18-64 years) sleep an average of 7.9h/24h (Wang et al., 2022). However, shiftworkers, who comprise 28% of the Canadian population, tend to experience insufficient sleep (<6.5h/24h). Several studies estimate sleep quantity losses for this population between 0.3h and 4.0h per day throughout the workweek, with poorer quality (i.e., disrupted) sleep, divided between a main sleep period and nap(s) (Akerstedt, 2003; Kecklund & Axelsson, 2016; Korsiak et al., 2018). Shiftwork involves working hours outside of standard daytime hours (e.g., 8h, 09:00 am – 5:00 pm), including very early morning, afternoon, overnight, or 24h shifts that may begin before 7:00 am or after 10:00 am (Cheng & Drake, 2016). Accordingly, shiftworkers are required to be awake for extended periods, and work and sleep at times outside of their natural circadian rhythm (i.e., predictable daily peaks and troughs in alertness). This results in poor sleep quantity and quality, and high levels of sleepiness (Akerstedt & Wright, 2009). In healthcare settings, shifts are typically 12h and may rotate between days and nights (e.g., 7:00 am to 7:00 pm), which can result in insufficient sleep. For example, nurses who work rotating 12h day/night shifts sleep an average of 5.4h-5.7h/24h throughout the workweek (Geiger-Brown et al., 2012) which is below the threshold required for sufficient sleep.

As a group, healthcare shiftworkers also show certain demographic trends that make this a particularly at-risk group warranting further study. For example, the majority of nurses working night or rotating shifts are female (92%), and are more likely to be under the age of 25, with <1 year of work experience (College of Nurses of Ontario, 2017; Novak & Auvil-Novak, 1996). In fact, many non-physician healthcare occupations (e.g., nurses, paramedics, technicians, support staff) require entry-level training in two-to-four-year college or university programs, allowing new graduates to begin working full-time between 20-22 years of age. These factors place healthcare shiftworkers at increased driving performance risk due to several reasons. First, younger drivers are more vulnerable to the effects of sleep loss than older drivers, due to brain maturation, lifestyle factors, and differences in self-regulation of driving behaviour (Cai et al., 2021; Scarpelli et al., 2021; Soleimanloo et al., 2017). Younger shiftworkers (e.g., nurses) are also known to have greater difficulty coping with fatigue and recovery between shifts compared to their older colleagues (Novak & Auvil-Novak, 1996; Winwood et al., 2006). Second, women and younger shiftworkers are more likely to obtain part-time or casual work contracts which can result in unpredictable scheduling with low levels of control (Statistics Canada, 2018; Williams, 2008). In Ontario the rate of part-time work is increasing among new-graduate nurses, with 42.5% of registered nurses aged 18-29 employed in part-time or casual roles, compared to 28.4% of those aged 30-54 years (Baumann et al., 2021; College of Nurses of Ontario, 2017). Unpredictable scheduling and/or low levels of control over work scheduling may decrease sleep quantity given the challenges of navigating competing employer demands and late notice for casual or call-in shifts, which result in reduced opportunity to sleep between work shifts. Yet, women and workers <24 years of age are underrepresented in existing research on shiftworker driving performance, while part-time workers are absent altogether (Knott et al., 2020).

The limited representation of female, younger, or part-time shiftworkers in driving studies suggests that selection bias may exist (Knott et al., 2020). The extant literature overemphasizes the examination of shiftworkers employed full-time in professional occupations such as medicine and policing, which require either extensive training or seniority to attain. This may result in a survivor cohort of healthy shiftworkers who better tolerate the demands of shiftwork, and inadvertently exclude those who cannot tolerate such demands (Kantermann et al., 2010). This selection bias may, in turn, result in underestimating the effects of shiftwork on driving performance, particularly for younger shiftworkers.

1.2 Impact of Insufficient Sleep and Sleepiness on Function

Adults require 7h to 8h sleep daily (i.e., 7-8h/24h) to maintain stable neurobehavioural and neurocognitive functions (Banks et al., 2017). Conversely, insufficient sleep quantity is shown to result in significant neurobehavioural and neurocognitive deficits, including slower reaction time, response disinhibition, and reduced situational awareness, information processing, vigilance, insight, judgment, risk perception, problem-solving, memory, and divided, selective, and sustained attention (Banks et al., 2017; Basner et al., 2013; Bonnet, 2011; Czeisler et al., 2016; Goel et al., 2009; MacLean, 2016; Watson et al., 2015). Impairments in one or more of these functions may compromise driving performance (Barco et al., 2012). In acute and chronic insufficient sleep, neurobehavioral deficits increase proportionally to the total number of hours of sleep loss incurred over subsequent days, otherwise known as the extent of accrued sleep debt (Banks et al., 2017).

To understand the impacts of insufficient sleep and sleepiness on function, it is also critical to understand the determinants of sleepiness beyond only sleep quantity and quality. These include a range of factors about the person, occupation, and environment. For example, other person-level factors aside from age include chronotype, alignment or misalignment of sleep and activity relative to the circadian rhythm, duration of wakefulness, acute versus chronic insufficient sleep, and the presence of medical or sleep disorders and/or related medications which affect the central nervous system (Bonnet, 2011; Roehrs et al., 2017). First, an individual's chronotype (i.e., preference for morningness or eveningness), results in significant differences in shiftworker sleep quality and quantity when there is a mismatch between circadian preference and shift assignment (Juda et al., 2013; Korsiak et al., 2018). Second, the oscillating circadian rhythm (i.e., twice-daily peaks of alertness and troughs of sleepiness) and the duration of sustained wakefulness interact to influence ones' homeostatic drive to sleep and thus, the onset of sleep versus wake behaviour (Achermann & Porbely, 2017; Czeisler & Buxton, 2017; Roehrs et al., 2017). Negative impacts on subjective and objective measures for sleepiness peak when a strong homeostatic sleep drive overlaps with circadian rhythm trough; this typically occurs in early-morning or mid-afternoon hours, and reduces after a sleep opportunity (Akerstedt & Wright, 2009; Matthews et al., 2012). The acute effects of sleep loss are magnified if sleep loss is repeated over subsequent days (i.e., chronic), such that the accrued sleep debt is proportional to the degree of deficits on subsequent days (Banks et al., 2017). Finally, diagnosed medical conditions that affect the central nervous system and contribute to excessive daytime sleepiness (e.g., Parkinson's' disease, narcolepsy) are also independent risk factors of poor driving outcomes (Bonnet, 2011; Roehrs et al., 2017). Additionally, prescription or over-the-counter medications, along with substances like caffeine, can modulate alertness or sleepiness (e.g., stimulant or sedatives). For example, more than three-quarters of healthcare professionals report using stimulants like caffeine, while 27% reporting using sedatives like sleep aids (Richards et al., 2018; Roehrs et al., 2017). Therefore, research protocols must take into consideration such person-level factors.

Sleepiness levels may also be influenced by shiftworkers' occupations and the environment within which they engage in these occupations. Occupation-related factors that increase sleepiness levels include tasks that require nil-to-low physical activity, last longer than 10 minutes, or where the participant is unable to set their own pace and must respond in a timely fashion to external events (Bonnet, 2011). Environmental factors that influence sleepiness include exposure to low levels of lighting and either high or low temperatures (Bonnet, 2011). Taken together, the multifactorial nature of factors influencing sleepiness at the level of the person, environment, and occupation has important implications for designing and interpreting research results (Kantermann et al., 2010). Thus, research design must include explicit health-related inclusion/exclusion criteria, address participants' use of stimulant or sedative medications or substances and consider both environmental and time-of-day influences to account for the influences of the circadian rhythm and duration of wakefulness. Such factors are important predictors of performance and subjective sleepiness, which in turn influence driving performance (Akerstedt & Wright, 2009; Banks et al., 2017).

Aside from biological predictors, numerous cultural, institutional, and contextual factors may also influence shiftworkers' sleep quantity (e.g., h/24h sleep obtained), quality (e.g., extent of disruptions during attempted sleep), and timing (e.g., when sleep opportunity occurs). Individuals in Western cultures often view sleep as more flexible in comparison to the highly-valued work and family demands (Barnes et al., 2012). For example, American physicians rated family, work, and leisure activities as higher priorities than sleep (Furgeson et al., 2018). This may explain findings that show sleep quantity is most negatively impacted during times of conflict between work and non-work demands (Barnes et al., 2012). The relationship between work-life conflict and sleep quantity is non-linear, such that individuals who report the highest levels of conflict between work- and non-work demands, unpredictable work schedules, or low control over work schedules, obtain a disproportionately lower sleep quantity (Arlinghaus et al., 2019; Barnes et al., 2012).

Taken together, such influences on the person, environment, and occupation may result in performance impairments, such as in driving. Further, the combined effects of shiftwork on sleep, sleepiness, and function suggests these effects may increase as the workweek progresses placing both the driver and other users with whom they share the road at increased risk for adverse events (e.g., crashes and/or crash-related injuries). For example, drivers with about 5h/24h sleep for one week demonstrate equivalent driving errors when compared to drivers legally impaired via a blood alcohol concentration (BAC) greater than 0.08 g/dL (Powell et al., 2001). This is significant given that shiftworkers may lose up to 4h/24h sleep each workday (Akerstedt, 2003). Further, 45% of healthcare shiftworkers report high subjective sleepiness, peaking at the end of each shift and at the end of each week (Geiger-Brown et al., 2012), and driving with high levels of subjective sleepiness possibly predicts increased risk for near-miss or crash events (Knott et al., 2020).

1.3 Insufficient Sleep and Fitness to Drive

1.3.1 Existing Guidelines

While insufficient sleep is a well-established significant risk factor for motor vehicle collisions (MVC) (Czeisler et al., 2016), there is little formal guidance related to determining whether a person’s fitness to drive may be compromised due to insufficient sleep. Fitness to drive is conceptualized as the driver’s ability (i.e., with or without the use of technology or adaptations for functional deficits) to control a vehicle, keep up with the flow of traffic, and adhere to local road and traffic laws (Brouwer & Ponds, 1994; Transportation Research Board, 2016). In Canada, fitness to drive determinations are based on functional ability, that is, the integration of a driver’s personal characteristics (e.g., physical strength and movement, vision, hearing, and cognition), taking into consideration insight and compensatory strategies, and often requiring a comprehensive driving evaluation, rather just a basis of a medical diagnosis (Canadian Council of Motor Transport Administrators, 2020). As such, identifying drivers who may be unfit to drive, one must consider whether an impairment is transient (e.g., post-surgical restrictions), episodic (e.g., epilepsy), or persistent in nature (e.g., Alzheimer’s disease) (Canadian Council of Motor Transport Administrators, 2020). Additional considerations include the driver’s record, results of functional or medical assessments, and the driver’s ability to implement appropriate modifications or compliance with medical treatment regimes.

With regards to sleep, sleep disturbance, or sleepiness, there are limited references within the Canadian National Safety Code for determining Driver Fitness (2020). This document addresses primary medical conditions and prescription medications (e.g., Parkinson's disease, traumatic brain injury, obstructive sleep apnea, narcolepsy) along with related concepts of sleep disturbance, sleepiness, sleep attacks, and prescription medication effects. Concerns pertaining to fitness to drive focus on daytime sleepiness, risk of sleep while driving, and cognitive impairments compromising attention or memory (Canadian Council of Motor Transport Administrators, 2020). Meanwhile, only a single statement references insufficient sleep: "*[i]n addition to sleep disorders, a number of other factors such as work schedules or lifestyle choices may result in inadequate nocturnal sleep. Regardless of the cause, the risks of excessive sleepiness for driving safety are similar" (p.224).* However, the guidelines do not define 'inadequate nocturnal sleep' as it relates to determining fitness to drive.

Published literature offers suggested thresholds for sleep quantity, below which drivers may be considered temporarily impaired or unfit to drive. In 2016, the American National Sleep Foundation Drowsy Driving Consensus Working Group published a multidisciplinary expert consensus statement (Czeisler et al., 2016) using a systematic review and multiple rounds of voting to reach a consensus on sleep quantity and driver fitness. This expert panel concluded that: (a) the "*vast majority"* of healthy drivers with ≤2.0h/24h sleep are impaired and thus unfit to operate a motor vehicle, and (b) *"most healthy drivers"* would "*likely"* remain impaired with 3.0h to 5.0h/24h sleep, though no consensus conclusion on medical fitness to drive could be rendered at this level due to insufficient data (Czeisler et al., 2016). Further, the group indicated additional factors might make certain individuals more vulnerable to sleep loss than others (e.g., chronic insufficient sleep, medical or sleep disorders, age, etc.).

More recently in 2021, Dawson and colleagues published a comprehensive review examining sleep quantity and driving impairments. The review draws parallels to alcohol-related driving impairments, as well as legal, sociocultural, and policy implications (Dawson et al., 2021). Authors concluded that: (a) for a vast majority of drivers, ≤5.0h/24h sleep would result in impaired driving performance akin to alcohol impairment, with (b) virtually all drivers impaired with ≤4.0h/24h sleep. Yet currently, sleep-related driving impairment is only illegal in state of New Jersey in the United States of America, whereby drivers are deemed too impaired to operate a motor vehicle if they had 0h/24h sleep (Dawson et al., 2021). A threshold of 24h of continuous wakefulness was established as equivalent to the driving performance of an individual with a BAC of 0.10%, suggestive of significant driving impairment – well beyond the current BAC 0.08% legal limit commonly used throughout North American jurisdictions (Dawson et al., 2021).

Importantly, both Czeisler et al. (2016) and Dawson et al. (2021) emphasize the importance of establishing clear guidelines to communicate a threshold of insufficient sleep, beyond which most drivers would be ‘deemed impaired’ or ‘unfit to drive’, akin to alcohol-impaired driving. Such evidence-informed guidelines are required in order to inform highway traffic laws, occupational health and safety legislation, establish the degree of legal liability on drivers and/or employers, and develop public-health campaigns to deter sleep impaired driving and shift public perception on this issue (Dawson et al., 2021). The latter is also important, because as Dawson (2021) opines, sleep impaired driving is currently viewed as an *“inadvertent, unavoidable, or implicit cost of other activities”* (p.3), such as parenting or *“highly socially desirable activities such as working in healthcare or emergency services”* (p.3). This contrasts with alcohol-impaired driving, which is viewed as a negative, purposeful, and deviant driving behavior, despite similar functional impairments at certain thresholds.

Taken together, evidence shows that insufficient sleep quantity can significantly impact driving performance. Specifically, healthy drivers below thresholds of <6.5h/24h sleep begin to experience cognitive deficits that can affect their driving, while ≤5.0h/24h sleep may significantly impair driving performance for the vast majority of drivers. Thus, quantifying the impact of shiftwork on sleep, sleepiness, and driving performance in healthcare workers is essential to inform mitigation strategies and to protect the driver and the public’s health.

1.3.2 Driving Behaviour Models

Michon's Model of Driving Behaviour (Michon, 1985) and the cognitive control hypothesis (Engstrom et al., 2017) inform the systematic approach used in this research to conceptualize how deficits arising from insufficient sleep may negatively impact driving performance.

Michon's Model of Driving Behaviour (Michon, 1985) is the most commonly used framework in the literature to explain driving behaviours. The model conceptualizes three hierarchical levels of driving behaviour based on the required level of cognitive function (Oppenheim & Shinar, 2011). The first level, strategic driving behaviours, requires the highest level of cognitive functioning (e.g., executive functions, insight, or problem solving to plan and adapt routes) (Michon, 1985). Errors in strategic driving behaviours may include failing to adequately plan or adapt to changing road conditions or driver capability due to impairments in executive function or insight. Second, tactical driving behaviours require intermittent conscious decision-making for negotiating on-road situations (e.g., avoiding obstacles or making turns) (Michon, 1985). Errors in tactical driving behaviours may include missing a turn or making an unsafe turn due to impairments in memory, attention, or judgment. Finally, operational driving behaviours require the most basic level of automatic responses to operate the motor vehicle, (e.g., pressing gas or brake pedals in response to traffic speeds) (Michon, 1985). Errors in operational driving behaviours may include failing to react to a sudden hazard due to episodes of hypovigilance or inattention.

The cognitive control hypothesis asserts that *"cognitive loading selectively impairs subtasks that rely on cognitive control but leaves automatic performance unaffected"*(Engstrom et al., 2017, p.736). In other words, under high relative cognitive demands, a drivers' performance will be more likely impaired in variable or novel tasks, but retained in more benign and routine driving functions (Engstrom et al., 2017). Driving behaviours may become automatic, e.g. described as effortless or unconscious control within routine driving environments and situations (Ranney, 1994). More experienced drivers have repeated exposure to a larger breadth of routine driving scenarios and stimuli demanding similar driving behaviour responses (Engstrom et al., 2017; Fuller, 2005; Ranney, 1994). Therefore, experienced drivers may have a greater range of automatic driving behaviours and habits in their routine driving, particularly when the driver has not experienced negative consequences arising from such behaviours (Ranney, 1994). Conversely, uncertain, novel, or hazardous driving situations would disrupt automatic responses and shift cognitive resources to enact a cognitively controlled response via operational, tactical, or strategic-level driving behaviour (Ranney, 1994). Driving tasks likely to require conscious cognitive control for decision making include actions using executive control and attentional effort to identify and respond to an unpredictable event such as a car suddenly pulling out from a parallel parked position (Engstrom et al., 2017; Oppenheim & Shinar, 2011).

Further, since the development of automatic driving behaviours is reliant on driving history, specifically duration, as drivers with less experience would have a smaller range of automatic driving behaviours and thus require greater cognitive control and increased cognitive resources in order to achieve similar driving demands to more experienced drivers (Ranney, 1994). The combination of a drivers' abilities, driving skills, driving history, and knowledge comprises a theoretical maximum driving competence; however competence may be temporarily reduced by factors such as insufficient sleep, distraction, or low motivation (Fuller, 2005). When a driver experiences increased task demands and their remaining cognitive resources are limited and may not be sufficient to effectively manage situations requiring conscious cognitive control (Fuller, 2005). Where the cognitive demands of driving stimuli or challenges exceed the drivers' abilities, (e.g., attention, reaction time), this may result in increased errors, near-misses, or collisions (Engstrom et al., 2017; Fuller, 2005).

1.4 Driving Performance Indicators

Driving performance is comprised of five primary components, including: (1) *driving history*, including the driving record, education, licensing; (2) *driving habits*, such as good or bad driving practices repeated over time; (3) *driving behaviours*, such as strategic, tactical, and operational level behaviours for vehicle control; (4) *driving abilities*, comprising the neurocognitive or neurobehavioural or sensory-perceptual skills required to control a vehicle, and (5) *driving skills*, including demonstrated operational or tactical level behaviours during a driving simulator assessment (Classen et al., 2017; Michon, 1985; Transportation Research Board, 2016). Further, driving performance assessment should consider a range of driving environments and conditions to which the driver may be exposed in real driving (Transportation Research Board, 2016). Given this broad range of outcome measures comprise driving performance, we can examine the areas in which preliminary data exist, and where gaps remain in knowledge related to driving performance in healthcare SW.

Literature on *driving history* of SW primarily focuses on the self-reported occurrences of sleep-related driving events (e.g., severe sleepiness, nodding off, or falling asleep). In Canada, 14.5% of all drivers reported nodding off or falling asleep in the prior year (Vanlaar et al., 2008). This is a stark contrast to data in SW, where between 67% and 80% of nurses working night shifts reported sleepy driving in the prior month (Novak & Auvil-Novak, 1996; Scott et al., 2007). Moreover, up to 95% of nurses reporting adverse driving events in the past year, such as missing turns, falling asleep while driving, or highway hypnosis, (i.e., memory gaps for parts of the drive), most often on the drive home from work after an extended period of wakefulness (Mulhull et al., 2019; Novak & Auvil-Novak, 1996; Scott et al., 2007). Outside of self-reported sleep-related driving events (e.g., severe sleepiness, nodding off, falling asleep) there is little information on other aspects of driving history, including citations or infractions on driving records, or occurrences of adverse driving events, and whether such instances differ significantly from those working regular dayshifts.

Existing research on *driving habits* relevant to sleep-related driving experiences primarily focuses on identifying drivers who are more likely to drive with sleepiness, and the types of countermeasures used to mitigate it. Limited data exists on SWs' driving habits, suggesting that some nurses may continue to drive with sleepiness due to a strong desire to arrive home promptly after work, and may tell themselves that they will make it safely to justify continuing to drive (Smith et al., 2019). Otherwise, research in this area arises from participant groups including national surveys of licensed drivers, and surveys, questionnaires, or interviews with younger drivers, university students, or those with poor sleep quality. Factors related to a driver's experience that are predictive of intention or willingness to drive with sleepiness include: younger drivers (Watling & Watling, 2021); those with a history of poor quality/quantity sleep and fatigue (Jiang et al., 2017); and those with prior sleep-related driving experiences, near misses, or traffic violations (Lee et al., 2016; Lucidi et al., 2006; Watling, 2020). Drivers with more experience driving with sleepiness perceive reduced negative consequences (e.g., lower probability and severity of potential harms arising from driving with sleepiness), and increased intention and willingness to engage in sleepy driving. Further, they are less likely to stop the car to address sleepiness, preferring instead to use countermeasures while continuing to drive (Lee & Beck, 2019; Lucidi et al., 2006). Drivers may use a variety of countermeasures to cope with sleepiness while driving (e.g., pulling over to nap, stretch, change drivers, or consume coffee). Roadside strategies are accepted as generally more effective and less risky to the driver, as enacting them requires the driver to cease driving (Nordbakke & Sagberg, 2007; Watling et al., 2015). Meanwhile, drivers more often choose to use in-vehicle countermeasures to increase alertness while continuing to drive (e.g., increase cold air or volume of music), despite evidence suggesting these are less effective and thus higher-risk choices (Anund et al., 2008; Watling et al., 2015). Though riskier, in-vehicle countermeasures are more commonly enacted than roadside countermeasures (Anund et al., 2008; Watling et al., 2015). This is problematic since a driver's history of sleepy driving, the effectiveness of countermeasures used to address sleepiness, and experiences of near-misses or crashes significantly predict sleep-related motor vehicle collision (MVC) (Schreier et al., 2018). Findings from existing research highlight areas of concern relevant to SW, given data pertaining to sleep quality and quantity, sleepiness, and driving history suggestive of frequent occurrences of sleep-related driving events. However, these data arise from general or related populations. Although this may partially inform SWs' decision-making, their context and experience leading to enacting driving habits are absent.

Research on *driving behaviours* in SW has primarily focused on the operational level (e.g., variability of speed or vehicle position within the lane) with limited information on tactical level driving behaviours (e.g., maneuvers required to avoid obstacles or engage in emergency braking); with no data on outcomes at the strategic-level driving behaviours (e.g., planning or adapting routes to driver status or road conditions) (Knott et al., 2020).

Further, there is a gap in self-reported or proxy-reported data using standardized questionnaires in this population to determine whether risky- or safe- driving behaviours may vary compared with the general driver populations or clinical populations.

As outlined in section 1.2, existing research regarding *driving abilities shows that* insufficient sleep can impair neurocognitive and neurobehavioural functions in several critical areas required for driving (Banks et al., 2017). These include attention (e.g., alternating, divided, selective or sustained), visual processing, concentration, information processing speed, judgment and insight, and visual perception (Transportation Research Board, 2016). Understanding how cognitive skills underly driving ability, one may consider various aspects of attention. For example, drivers must alternate attention between various stimuli to monitor traffic conditions before engaging in lane changes; divided attention between both roadway and in-vehicle information; select pertinent information from the roadway while ignoring irrelevant information; and sustain attention and vigilance throughout the duration of the drive (Banich, 2004; Barco et al., 2012). Further, visual and information processing speed are required to perceive, react, and adjust to traffic conditions in a timely fashion. This allows the driver to meet the demands of the driving environment, while using appropriate judgement to select an appropriate response in a particular circumstance (Banich, 2004; Barco et al., 2012).

Finally, *driving skills* to date have been evaluated via driving simulator studies, closed-course in-vehicle studies, or self-reported naturalistic driving studies. Existing simulator studies in shiftworkers focus on predictable and monotonous low-complexity highway driving scenarios, purposely designed to maximize sleepiness and challenge vigilance and attention (Knott et al., 2020). Such monotonous scenarios primarily elicit automatic driving behaviours since novel or variable situations requiring conscious control are absent. Yet, 41% of sleep-related crashes occur in urban environments under low-speed (<60km/h) and high traffic density conditions (Filtness et al., 2017). Such high-density conditions require greater cognitive resources to exert cognitive control and enact more complex driving behaviour, thus challenging other known areas of neurocognitive impairments arising from insufficient sleep, as suggested by the cognitive control theory (Knott et al., 2020; Ranney, 1994).

Consistent with the low-complexity automatic driving behaviours afforded in these existing driving simulator studies, driving performance measures primarily used outcome measures requiring the least demanding operational-level outcomes (e.g., standard deviation of lateral position or speed) (Knott et al., 2020). Researchers have called for examining driving performance in realistic and more complex driving environments, representative of every-day real-world driving that integrates diverse conditions and outcome measures, including tactical and strategic level outcomes (Knott et al., 2020; Liu et al., 2009; Soleimanloo et al., 2017). Few naturalistic studies have examined SWs' sleepiness and driving performance during typical work-week commutes using SWs' own vehicle or relying on tracked outcomes via self-reported driving logs. Available studies of this kind found shiftworkers commuting home post-night-shift (versus pre-shift) had increased subjective and objective measures of sleepiness, increased adverse driving events on commutes in a variety of lengths and urban, suburban, and highway driving environments (Anderson et al., 2018; Ftouni et al., 2013; Green et al., 2020; Mulhull et al., 2019). Further, younger workers were more likely to report higher levels of sleepiness, and those with high sleepiness were more likely to report adverse driving events (Green et al., 2020). However, between-groups differences in adverse driving events for shiftworker and non-shiftworker groups have not yet been established.

1.5 Dissertation Rationale

The rationale for this dissertation derives from three primary fronts: (1) addressing the representativeness of shiftworker participants to mitigate impacts of selection bias; (2) advancing the understanding of shiftworkers' driving habits and coping strategies used to mitigate insufficient sleep and sleepiness while driving; (3) addressing the limitations in existing research study designs to understand differences in shiftworker and non-shiftworker driving performance, including naturalistic driving environments representative of real-world driving.

First, as mentioned at the outset of this literature review, healthcare shiftworkers, women, younger workers, and those in part-time employment have been historically underrepresented in research on insufficient sleep and driving. Yet, healthcare staffing statistics suggest that these are the very groups that are most likely to be employed in shiftwork (College of Nurses of Ontario, 2017; Gold et al., 1992; Novak & Auvil-Novak, 1996). This gap in knowledge, combined with research indicating younger drivers perform more poorly under conditions of insufficient sleep suggest that healthcare shiftworkers may be particularly at-risk group warranting further study on sleep, sleepiness and driving performance.

Second, given that SWs routinely experience decreased quality and quantity of sleep, they are more likely to experience sleepy driving. However, there is limited evidence on how shiftworkers cope with insufficient sleep and sleepiness when driving, and how this may inform their enactment of driving habits in such circumstances. While findings derived from population-level surveys, or studies with similar at-risk populations (e.g., younger drivers, university students, or those with poor sleep) suggest trends applicable to shiftworkers, these data are not specific to understanding the contextual realities and experiences of shiftworkers. Better understanding shiftworkers' experiences with sleepy driving and adverse driving events, motivations to engage in sleepy driving, and how drivers choose (or do not choose) to enact countermeasures may aid in developing future interventions (Watling et al., 2015), for driving risk reduction.

Third, methods used in existing research may underestimate the effects of insufficient sleep on driving performance in shiftworkers (Knott et al., 2020). For example, the majority of research is comprised of within-subjects designs comparing shiftworkers' driving performance pre- and post-shift or between work and non-work days (Knott et al., 2020). When relying on one full night of sleep to remediate sleep debt, such studies may not have had sufficient washout periods between experimental and control states to theoretically return to baseline neurocognitive function. Since sleep debt accrues over time, some shiftworkers may require 2-4 full nights of sleep to return to baseline functioning (Akerstedt et al., 2000). Therefore, using a comparison group of non-shiftworkers employed in healthcare may provide a more robust comparison group to better estimate where differences in driving performance may exist. Further, existing research focuses on narrow definitions of driving performance, primarily reliant on operational level of driving behaviours in simulated or closed-track driving scenarios using low-complexity monotonous highway driving (Knott et al., 2020). While challenging aspects of vigilance and attention, such conditions may not sufficiently challenge the cognitive demands required in real-world driving environments. Further, driving performance is comprised of driving history, driving habits, driving behaviours, driving abilities, and driving skills, typically evaluated in a range of environments and conditions to which the driver may be exposed in real driving (Classen et al., 2017; Michon, 1985; Transportation Research Board, 2016). Thus, considering a multi-faceted definition of driving performance may advance understanding of where differences may exist, and aid in identifying drivers most at risk for adverse driving outcomes.

1.6 Purpose of this Dissertation

The purpose of this dissertation is to examine the effects of sleep, sleepiness, and driving performance in healthcare shiftworkers (SW) using a mixed-methods approach. As shown in Figure 1-1, the dissertation includes three aims.

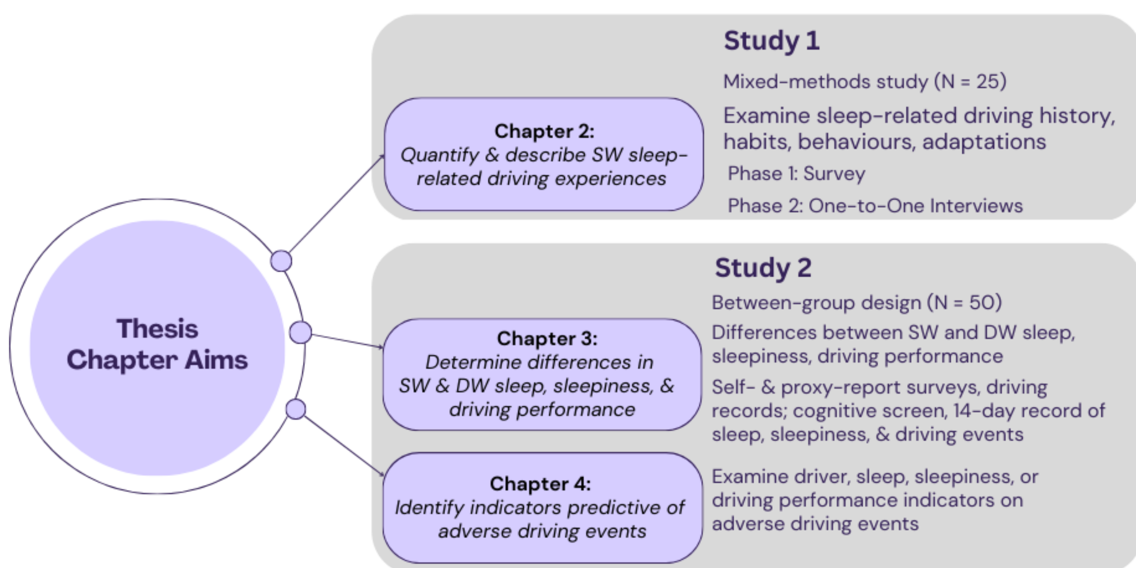

Figure 1-1 Dissertation Aims

Chapter 2 quantifies and describes healthcare SWs' sleep-related driving experiences, driving habits, and driving behaviours through a mixed-methods study using survey and interview data. Furthermore, this study aims to advance the understanding of healthcare SWs' sleep-related driving experiences, and how contextual elements may influence healthcare SWs' occupational adaptations to meet the demands of driving with insufficient sleep or sleepiness. The findings of this study will aid in developing intervention strategies relevant to the lived experiences and contexts of shiftworkers.

Chapter 3 aims to determine the differences in sleep, sleepiness, and driving performance between SW and day workers (DW) (i.e., two-group design) using an expanded operationalization of driving performance comprised of driving history, driving habits, driving behaviours, driving abilities, and driving events. We hypothesized that SW would demonstrate poorer sleep, higher levels of sleepiness, and poorer driving performance (versus DW). Findings will aid in developing a more fulsome understanding of healthcare SWs' driving performance across a broad spectrum, and thus inform future potential interventions targeting relevant aspects of driving performance.

Chapter 4 aims to identify indicators (e.g., driver demographics, sleep, sleepiness, or driving performance indicators) that may predict the total number of adverse driving events reported in a 6-week period. It is hypothesized that SW status, younger drivers, those with lower overall sleep quality and quantity, higher levels of sleepiness, and a higher self-reported 1-year history of adverse driving events, may predict the total number of adverse driving events experienced.

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Chapter 2

2 *"The car drives itself home":* Examining Healthcare Shiftworkers' Sleep-Related Driving Experiences Using Mixed-Methods[1]

Shiftwork employment is highly prevalent in the healthcare sector – with 45% of all healthcare workers and up to 80% of paramedics working rotating day/night shifts (Fischer & MacPhee, 2017; Williams, 2008). This rate of shiftwork employment is commensurate with staffing logistics required to deliver 24h care in hospital and pre-hospital emergency settings. Secondary to extended periods of wakefulness and working and sleeping outside of natural circadian rhythms, approximately 75% of shiftworkers report poor sleep quantity or quality and/or high levels of sleepiness (Akerstedt & Wright, 2009). Obtaining <6.5h sleep per 24h is considered insufficient sleep, and negatively effects cognitive functioning in a dose-dependent relationship in key areas required for driving (Banks et al., 2017; Barco et al., 2012).

Globally, 10-20% motor vehicle collisions (MVC) may be attributed to sleep-related factors (e.g., fatigue) (Thomas et al., 2021). Risk factors for sleep-related MVC include shiftwork, overtime, insufficient sleep and/or extended periods of wakefulness before driving (Stutts et al., 2003); and/or drivers who are younger, male, or living with medical and/or sleep disorders (Thomas et al., 2021). Further, exposure to nightshifts is a likely predictor of adverse driving outcomes, while high subjective sleepiness is a possible predictor for adverse driving outcomes (Knott et al., 2020). Multiple risk factors may apply to healthcare shiftworkers (HCSW), highlighting the necessity of enhancing knowledge on driving outcomes in this historically under-studied group (Knott et al., 2020).

Existing data show that 67% to 80% of HCSW report a driving history of sleep-related driving events, (e.g., severe sleepiness) in a one-month period (Novak & Auvil-Novak, 1996; Scott et al., 2007). Further, a driving history of adverse driving events (e.g., wandering lanes, missing turns,

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[1] A version of this manuscript is in preparation for submission to the journal *Transportation Research Part F: Traffic Psychology and Behaviour.*

falling asleep, memory gaps for parts of the drive), is reported by up to 95% of nurses in a one-year period, most commonly when driving home from nightshifts (Mulhull et al., 2019; Novak & Auvil-Novak, 1996; Scott et al., 2007).

Driving habits (e.g., good or bad driving practices repeated over time) (Classen et al., 2017; Transportation Research Board, 2016) relevant to sleep-related driving events include continuing to drive despite sleepiness and the types of countermeasures (e.g., adaptations) drivers may choose to implement to reduce sleepiness. Overall, a driver’s willingness and intent to engage in driving with sleepiness are influenced by myriad factors relating to the driver’s experiences, perceptions, and motivations. An increased likelihood of continuing to drive with sleepiness is observed in drivers with poor sleep quality or quantity, a history of sleep-related and/or near-miss driving events, and in those who are younger (Lee et al., 2016; Lucidi et al., 2006; Watling, 2020; Watling & Watling, 2021). Further, drivers who intend to drive with sleepiness indicate higher confidence in their ability to safely overcome sleepiness and greater control over their driving outcomes (Lee & Beck, 2019; Watling, 2020); more confidence in countermeasure used (Nordbakke & Sagberg, 2007; Watling et al., 2014); and more positive attitude and peer acceptance towards driving with sleepiness (Jiang et al., 2017; Lee et al., 2016). Countermeasures used to address sleepiness while driving include both roadside strategies requiring the driver to stop driving (e.g., pulling over to rest or change drivers), or in-vehicle strategies enacted while continuing to drive (e.g., cold air, music, eating) (Nordbakke & Sagberg, 2007; Watling et al., 2015). Though riskier, in-vehicle countermeasures are more commonly enacted than roadside countermeasures (Anund et al., 2008; Watling et al., 2015). Factors such as younger age, less driving experience, lower sleepiness levels, and sleep-related driving history may influence driver’s to choose in-vehicle while continuing to drive, instead of stopping driving (Anund et al., 2008; Lucidi et al., 2006; Watling et al., 2015). Scant data exists on HCSWs’ driving habits related to sleep. Existing data suggest that HCSWs may continue to drive with sleepiness using countermeasures they learned informally from colleagues or personal experience, combined with a strong desire to return home and convincing themselves they will arrive safely despite sleepiness (Smith et al., 2019).

Driving behaviours are commonly conceptualized using Michon’s Model of Driving Behaviour (Michon, 1985), via three hierarchical levels based on cognitive complexity and time demands

(Oppenheim & Shinar, 2011). From most to least complex, the levels include strategic (e.g., high-level cognition required to plan and adapt routes before or during a drive), tactical (e.g., intermittent decision-making to navigate on-road obstacles, turns), and operational (e.g., basic automatic responses to interact with equipment such as pressing the gas to adjust speed in response to traffic conditions) (Michon, 1985). To date, research on countermeasures used to address sleepiness while driving primarily focus on operational-level driving behaviours (e.g., interacting with vehicle equipment to enhance alertness of driver via changing air flow, music, speed), with limited discussion of tactical or strategic behaviours (e.g., stopping driving to rest, adapt to driver or traffic conditions). Further, existing data focuses on in-the-moment coping with sleepiness once it occurs and does not address pre-driving adaptations, nor is it specific to shiftworkers' contexts.

Integrating an occupation-focused perspective may aid in understanding HCSWs' driving experiences and contextual factors influencing driving habits in the context of insufficient sleep and sleepiness. Occupational adaptation is a dynamic and ongoing process of adapting routines and integrating strategies to meet the required demands for an individuals' roles and responsibilities (Walker, 2001). Given this, the use of routines, strategies or countermeasures while driving to mitigate the frequency or intensity of driving with sleepiness may be conceptualized as occupational adaptations used to meet the demands of driving, in the context shiftwork, insufficient sleep and sleepiness. Occupational adaptations may also include pre-drive choices, such as to adapting routines to enhance sleep quantity or reduce sleepiness, modifying driving demands via deciding whether (or not) to drive or use alternative transportation (e.g., transit, carpooling), or modify one's driving demands. However, an individual's occupational adaptations may vary, based on the occupational possibilities that they perceive as available to them given the contexts of their social, cultural, institutional or physical environments (Gallew & Mu, 2004; Walker, 2001). Occupational possibilities are comprised of taken-for-granted approaches to occupational adaptations that one views as ideal or possible, shaped by dynamic processes, social structures, and factors such as age, gender, personality type. (Laliberte Rudman, 2010). Therefore, the range of occupational possibilities viewed as ideal or possible by individual SWs may vary based on such intersections, despite SWs engaging in similar occupations (e.g., working, sleeping, driving). Given the myriad of contextual factors influencing an individual's occupational adaptations and possibilities, storied accounts of SWs' sleep-related driving experiences may expand our understanding of SWs' occupational adaptations within their broader life context.

Existing research examining sleep-related driving habits focuses on quantitative data predicting drivers' intent or willingness to drive with sleepiness and choice countermeasures used to address sleepiness. However, this data is not specific to SW's context, and there is limited data on driving history or behaviours. Moreover, research examining SWs' occupational adaptations focus on general adaptations to the demands of shiftwork employment (Novak & Auvil-Novak, 1996; Walker, 2001), with sparse qualitative data on SWs' driving experiences, factors related to sleepiness and/or fatigue, and motivational factors to continue sleepy driving (Smith et al., 2019). Therefore, collecting quantitative and qualitative data would enable researchers to obtain complimentary data to enable a more fulsome understanding of the research question than would be possible using one approach in isolation (Creswell, 2014). Specifically, quantitative data on HCSW's driving history, habits, and behaviours would provide foundational information in these areas, and subsequently allow the selection of participants with relevant lived experiences to further explore their sleep-related driving experiences, contexts, and adaptations.

2.1.1 Objective

The purpose of this mixed-methods study is two-fold. First, to quantify and describe HCSWs' self-reported driving history, habits, and behaviours, as well as sleep and sleepiness. Second, to advance the understanding of HCSWs' sleep-related driving experiences and how contextual elements may influence HCSWs' occupational adaptations to meet the demands of driving with insufficient sleep or sleepiness.

2.2 Methods

The Health Sciences Research Ethics Board at Western University granted ethics approval for this study (ID# 115781). A copy of the approval letter is in Appendix A. This manuscript adheres to the Mixed Methods Article Reporting Standards (MMARS) (Levitt et al., 2018).

2.2.1 Study Design

This study used a mixed-methods sequential explanatory, quantitative dominant design (Creswell, 2014) and was comprised of two phases. Phase One included a quantitative online survey examining HCSW sleep and sleepiness, and driving history, habits and behaviours. Survey results were then used to inform participant selection for Phase Two, which consisted of one-to-one interviews (Stanley, 2015). As such, quantitative data informed the sampling frame for the qualitative phase, allowing the selection of participants with recent lived experiences relevant to the research question. Furthermore, the quantitative data was used to tailor the interview questions to each participant's survey responses (Creswell, 2014). This research engaged a pragmatic worldview that assumes collecting and analyzing both quantitative and qualitative data will provide complementary information to aid in a multi-dimensional understanding of the research question (Creswell, 2014; Creswell et al., 2011).

2.2.2 Procedure

2.2.2.1 Setting

This study was conducted in Southwestern Ontario, Canada between October 2020 and April 2021. In adherence with COVID-19-related public health mandates, all data collection occurred online, using Western University institutional licenses for Qualtrics (online survey) and Zoom (videoconferencing). Remote data collection is an established and acceptable approach to collect survey and interview data, and may reduce participants' time burden by time to participate (Varma et al., 2021). While potential drawbacks to remote data collection include internet connectivity or technology access (Varma et al., 2021), no participants indicated technological barriers in completing procedures in this study.

2.2.2.2 Participants

The sample size (*n* = 25) for this mixed-methods study was determined to ensure an adequate sampling frame for the Phase Two interviews, and proactively plan for potential participant attrition (e.g., eligibility for Phase One, consent and Eligibility for Phase Two, or loss to follow up). For qualitative descriptive research, a range between 10-20 participant interviews is recommended to obtain sufficiently rich data for analysis from a homogeneous sample (Braun & Clarke, 2013). Using an estimate of 67% to 95% of nurses reporting drowsy driving, near-misses, or crashes in the past year (Novak & Auvil-Novak, 1996; Scott et al., 2007), a sample size of 25 would result in 16 to 20 Phase Two-eligible interview participants, and facilitate a 10% buffer for potential attrition in each Phase One and Two.

Twenty-five HCSW were recruited via electronic advertisements to healthcare employers (e.g., hospitals, municipal paramedic services), and via social media (e.g., Facebook). Informed consent for survey, interview, interview audio recording, and member checking session were obtained electronically via Qualtrics webform. Verbal consent for audio recording the interview was re-affirmed at the outset of the interview. Participants completing the survey could opt to enter a random draw for one of two $20 e-gift cards. Interview participants were each provided a $15 e-gift card as a token of appreciation for their time.

2.2.2.3 Eligibility

Phase One. Participants answered a series of questions via Qualtrics to establish eligibility per criteria in *Table 2-1,* to ensure relevant work and driving history, language ability, and health status. Exclusion criteria addressed health-related factors such as specific self-reported medical diagnoses, use of prescription medications affecting the central nervous system, or a score of >15/24 on the Epworth Sleepiness Scale (ESS) (Johns, 1991) which validly indicates an underlying sleep-related pathology. These health-related exclusion criteria were selected due to their potential to independently interfere with sleep, sleepiness, alertness, or operation of a motor vehicle.

Phase Two. Participants' survey responses were examined to determine eligibility for Phase Two. Participants reporting a 1-year driving history positive for one or more episodes of driving with severe sleepiness, nodding off, or falling asleep at the wheel were eligible to participate in the interview. These eligibility criteria were selected to promote a homogeneous group of participants with relevant sleep-related driving experience(s), who may be able to provide rich, detailed information for analysis (Braun & Clarke, 2013).

Table 2-1 Eligibility Criteria

Inclusion Criteria	Exclusion Criteria
Phase One: Online Survey	
1. Employed in healthcare sector for ≥1 year 2. Work 12h rotating day/night shift schedule (i.e., full-time equivalent basis) 3. Fully licensed driver 4. Drive >1000 km/year 5. Drive to/from work	1. Neurological, psychiatric, or sleep disorder diagnosis known to independently impact fitness to drive, per self-report 2. Prescription stimulant or sedative medication, per self-report 3. Score of >15/24 on Epworth Sleepiness Scale (Johns, 1991), suggesting severe daytime sleepiness
Phase Two: One-to-One Interview	
1. Completed survey with ≥1 sleep-related driving event (e.g., driving with severe sleepiness, nodding off while driving, and/or falling asleep while driving) in the past year	1. Did not consent to further study activity beyond Phase One

2.2.2.4 Phase One Survey

2.2.2.4.1 Data Collection

The online survey items included standard demographic questions, driving history, self-reported sleep quantity, and standardized questionnaires (see *Table 2-2*). Questionnaires included the Epworth Sleepiness Scale (ESS) (Johns, 1991), Driving Behaviour Questionnaire (DBQ) (Cordazzo et al., 2016), and the Scale of Fatigue Driving Behavior Questionnaire (SFDB) (Jiang et al., 2017).

2.2.2.4.2 Data Analysis

Survey responses were exported from Qualtrics into SPSS v.27.0 (IBM, 2022) for analysis. Descriptive statistics (e.g., percentage, mean, median, standard deviation, and *z*-score, where applicable) were computed. One-sample *t*-test was computed to identify whether Phase One participant responses differed from published normative data on the DBQ (Cordazzo et al., 2016) and SFDB (Jiang et al., 2017) using a two-tailed $\alpha = .05$. Subgroup analyses were completed to independently characterize each group (i.e., Phase Two eligible participants, others who did not qualify), and examine patterns and trends to facilitate further discussion with qualitative data.

Table 2-2 Phase One Survey Items

Questionnaire or Measure (Author, Year)	**Domain**	**Description**
Epworth Sleepiness Scale (ESS) (Johns, 1991)	Level of daytime sleepiness	Eight situations are rated for likelihood to fall asleep, from 0 (i.e., never) to 3 (i.e., high chance). Total scores range from 0 to 24. The level of daytime sleepiness is classified as: Lower Normal (i.e., score 0-5), Upper Normal (i.e., score 6-10), Mild Excessive (i.e., score 11-12), Moderate Excessive (i.e., score 13-15), or Severe Excessive (i.e., score >15, indicates underlying sleep-related pathology).
Workweek Sleep Quantity	Hours of sleep	Self-reported total number of hours of sleep per 24h (h/24h), including both main sleep and naps, before each shift (shift 1 – shift 4) in the past workweek.
Driving Behaviour Questionnaire (DBQ) (Cordazzo, et al., 2016)	Frequency of risky driving behaviours	Sixty-five items on risky driving behaviours rated from 0 (i.e., never) to 5 (i.e., always) across four subscales: Inattention Errors (i.e., IE, 32 items), Age-Related Problems (i.e., ARP, 6 items), Distraction and Hurry (i.e., DH, 20 items), and Aggressive Violations (i.e., AV, 7 items).
Scale of Fatigue Driving Behaviour Questionnaire (SFDB) (Jiang, et al., 2017)	Fatigued driving perceptions and behaviours	Fourteen items on fatigued driving perceptions and behaviours rated from 1 (i.e., strongly disagree/unlikely) to 5 (i.e., strongly agree/likely) across five subscales: Subjective Attitude (i.e., SA, 2 items), Subjective Norms (i.e., SN, 3 items), Perceived Behavioural Control (i.e., PBC, 3 items), Fatigued Driving Intention (i.e., SBI, 3 items), Fatigued Driving Behaviour (i.e., SB, 3 items).
Driving History Form	History of sleep-related and adverse driving events	Participants rated if they experienced sleep-related driving events ever, in the past year, and/or past month: i.e., (1) falling asleep, (2) nodding off even for only a moment, and/or (3) having severe sleepiness. Participants experiencing sleep-related driving events were asked how often these occurred in the past month, as well as if they had any adverse driving events in the past year (e.g., crossing the center lane, missing turns/lights, memory gaps, crashes). Adverse driving events were categorized as being sleep-related, inattention, hazardous, or violations.
Driver and Vehicle Characteristics	Basic driver and vehicle information	Formal driver training (basic, advanced); kilometers driven annually; whether primary personal vehicle equipped with In-Vehicle Information Systems (IVIS, e.g., blind-spot warning system) or Advanced Driver Assistance System (ADAS, e.g., lane-keeping assist).

2.2.2.5 Phase Two One-to-One Interview

2.2.2.5.1 Data Collection

Participants with a positive 1-year driving history for severe sleepiness, nodding off, or falling asleep were invited to complete a 1-hour individual interview with the PhD Candidate. A semi-structured interview guide (*Appendix B*) was piloted with health-sciences qualitative researchers and refined to promote clarity. Open-ended questions explored participants' sleep-related driving experiences and perceptions, occupational adaptations for managing sleep and driving, contextual factors influencing their choices, and any changes in their experiences since the onset of the COVID-19 pandemic.

2.2.2.5.2 Data Analysis

Data items included interview transcripts and field notes. Interviews were transcribed verbatim by two trained research assistants, validated by the PhD Candidate and exported into NVivo software for coding (QSR International, Version 12.1, 2018). The PhD Candidate completed field notes following each interview, including response summaries, researcher reflections on similarities or differences to other interviews, notable data items of analytic impressions. Reflexive journaling entries were used to aid in thematic analysis and theme development using an inductive, data-driven, six-phase process: (1) becoming familiar with the data set; (2) generating initial codes; (3) developing initial themes; (4) reviewing potential themes; (5) defining and naming themes; and (6) producing the written report (Braun & Clarke, 2006, 2013). Coding initially foregrounded participants' semantic or descriptive meanings, evolving into more latent themes meaningfully related to the research question (Braun & Clarke, 2006, 2013). Any participant quotes used to illustrate and support themes and subthemes are attributed to pseudonyms to retain anonymity, and their role as registered nurse (i.e., RN), or paramedic (i.e., EMS) provided for context.

2.3 Results

2.3.1 Participant Flow

Twenty-five participants consented for the Phase One survey (*Figure 2-1)*. When screening for study eligibility, four participants were excluded for: not having a full driver's license (*n* = 1), not being a shiftworker (*n* = 1), scoring >15/24 on the ESS (*n* = 1), or for having a diagnosed medical condition (*n* = 1). Accordingly, 21 participants were eligible to complete the Phase One survey; 20 of whom completed the survey and were screened to undergo Phase Two of the study. Eighteen participants were eligible for Phase Two, with a 1-year driving history showing one or more episodes of sleep-related driving events, with 13 participants ultimately completing interviews.

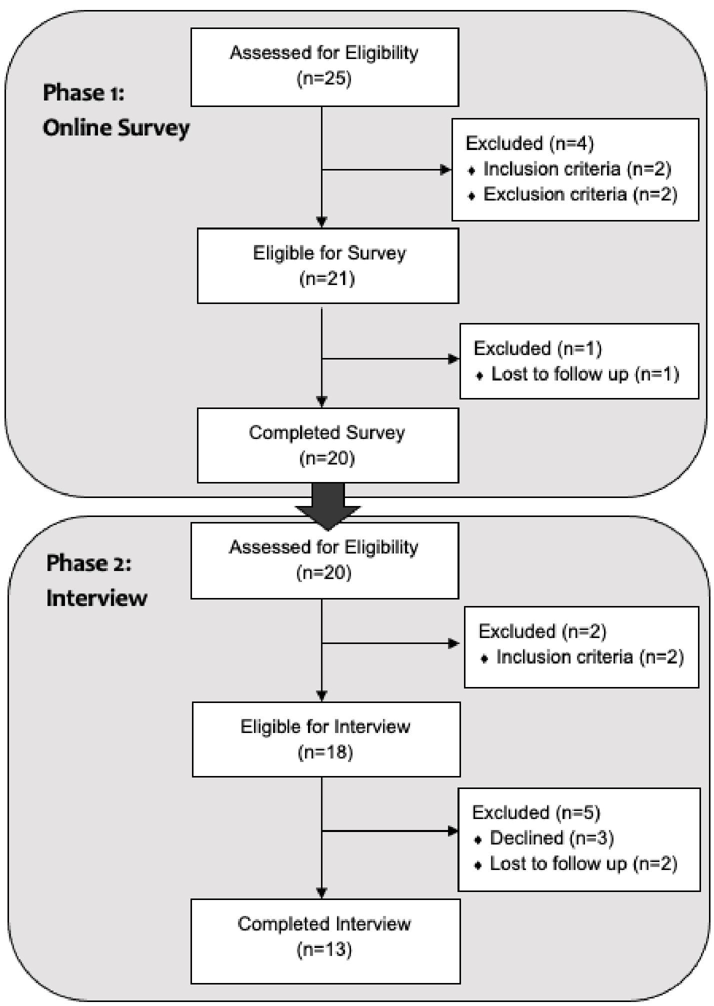


Figure 2-1 Participant Flow Diagram

2.3.2 Participant Characteristics

As shown in Table 2-3, participants for Phase One of the study were majority female (80%), Caucasian (100%), with a median age of 29.5 years (*R* = 21-58 years). Majority were employed full-time as nurses (*n* = 15) or paramedics (*n* = 5) with one employer (70%). Participants were employed as HCSW for a median of 7.5 years (*SD* = 8.7), working a mean of 13.6 shifts (*SD* = 3.3) in the past month. While 80% completed basic formal driver education, 15% completed both basic and advanced formal driver training. Few participants reported driving vehicles with advanced driving technology. Twenty percent drove vehicles with In-Vehicle Information Systems (IVIS, e.g., blind-spot warning system), with just 15% using both IVIS and Advanced Driver Assistance=-Systems (ADAS, e.g., land keeping assist).

Table 2-3 Participant Characteristics

Characteristics	All Phase One Participants (N = 20)	Phase Two eligible participants (*n* = 18)	Other Participants (*n* = 2)
Age (years)	29.5 ± 9.6 (21-58)	32.0 ± 9.7 (21-58)	27.0 ± 0 (22-31)
Sex			
Female	80%	75%	100%
Male	20%	25%	—
Ethnicity			
Caucasian	100%	100%	100%
Level of Education			
College diploma	60%	61%	50%
Undergraduate degree	40%	39%	50%
Occupation			
Nurse	75%	78%	50%
Paramedic	25%	22%	50%
Primary Employment Status			
Full time, 1 job	70%	72%	50%
Full time, >1 job	15%	17%	—
Part time, with call-in (FTE[1])	15%	11%	50%
Shiftwork experience (years)	7.5 ± 8.7 (1-36)	7.5 ± 9.0 (1-36)	5.5 ± 0 (2-9)
Number of shifts, past month	13.6 ± 3.3 (6-20)	14.0 ± 2.8 (8-20)	8.0 (6-10)
No. shifts with overtime	1.5 ± 2.0 (0-8)	1.3 ± 2.1 (0-8)	0.5 (0-1)
Longest shift duration (h)	12.6 ± 0.75 (12-14)	12.0 ± 0.7 (12-14)	13.0 (12-14)
Usual shift duration (h)	12.0	12.0	12.0
Driver Education			
Basic	80%	94%	100%
Advanced	5%	5%	—
Basic and Advanced	15%	20%	—
Vehicle Technology[2]			
None	60%	61%	50%
IVIS[3] only	20%	17%	50%
IVIS and ADAS[4]	15%	17%	—

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. [1]FTE = Full-time equivalent work hours. [2]Vehicle technology includes participants' own vehicles. [3]IVIS = In-Vehicle Information System. [4]ADAS = Advanced Driver Assistance System.

2.3.3 Phase One Survey Results

2.3.3.1 Sleep-Related and Adverse Driving Events

As shown in *Table 2-4*, 18 participants (90%) reported experiencing sleep-related driving events in the past year and were eligible for the Phase Two interview, hereafter referred to as *"Phase Two eligible participants"*. Two participants reported no such history and were thus ineligible (i.e., hereafter referred to as *"other participants"*). Sleep-related driving events in the past year included: severe sleepiness (90%), nodding off (40%), or falling asleep (20%). In the past month, Phase Two eligible participants reported experiencing severe sleepiness (94%, 1-50 episodes), nodding off (28%, 1-7 episodes), and falling asleep (11%, 5 episodes each). Further, Phase Two eligible participants more frequently reported continuing to drive after noticing sleepiness (i.e., *Mdn* = 9.5/10), where 1 = never and 10 = frequently, compared to others (i.e., *Mdn* = 3/10).

Table 2-4 Occurrence of Sleep-Related Driving Events in Phase One Participants

Sleep-Related Event	**All Respondents** (N = 20)	**Phase Two Eligible Participants** (n = 18)	**Other Participants** (n = 2)
Severe sleepiness			
Past 12 months	90%	100%	—
Past 1 month	85%	94%	—
No. times in past month	—	5.0 ± 11.3 (1-50)	N/A
Nodding off			
Ever	75%	78%	50%
Past 12 months	40%	44%	—
Past 1 month	25%	28%	—
No. times in past month	—	1.0 ± 2.3 (1-7)	N/A
Falling asleep			
Ever	40%	39%	50%
Past 12 months	20%	22%	—
Past 1 month	10%	11%	—
No. times in past month	—	2.5 ± 2.9 (0-5)	N/A
Continuing to drive after noticing sleepiness (1 = never, 10 = frequently)	9.0 ± 2.9 (2-10)	9.5 ± 2.6 (2-10)	3.0 ± 0 (3-3)

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data.

Phase Two eligible participants (*N* = 18*)* reported whether they experienced any adverse driving events in the past month, presented in *Table 2-5*. Overall, 94% reported one or more adverse driving events with a median 1-year history of 15.5 ± 24.4 (*R* = 1-79) total events. The most to least frequent reported adverse events included: startling awake in the same lane (78%), experiencing memory gaps (67%; i.e., no clear recollection of driving the past several kilometers), hitting 'rumble strips' at the side of the highway (39%), missing an intended light or turn (33%), crossing the centre line into oncoming traffic (28%), wandering into another lane (28%), arriving at an unintended destination (11%), crashing with no injury (11%), crashing with injury (6%), and an occurrence with another driver honking (6%).

Table 2-5 Adverse Driving Events in the Past 12 months, reported by Phase Two eligible participants

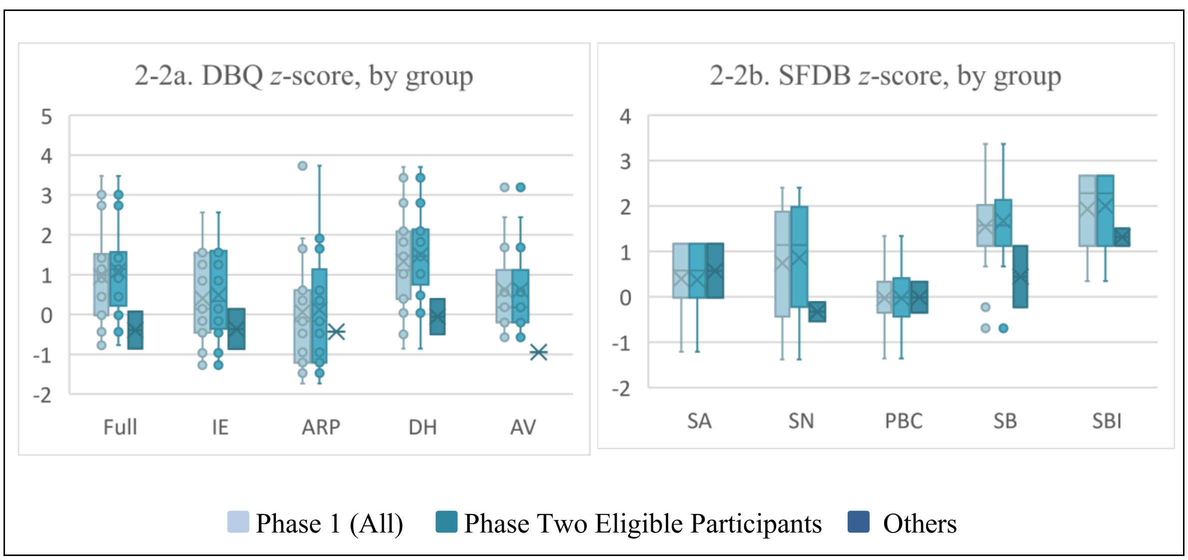
Adverse Driving Events	**Percent of Phase Two eligible participants** *(N = 18)*	**Number of Events, Past Year** *M±SD (Range)*
Total reporting any adverse driving event	94%	15.5 ± 24.4 (1-79)
Startled awake, same lane	78%	3.0 ± 13.4 (1-48)
Memory gaps	67%	8.0 ± 16.6 (2-60)
Ran onto 'rumble strips' at edge of road	39%	4.0 ± 3.0 (1-10)
Missing intended light / turn	33%	1.5 ± 1.9 (0-5)
Crossed centre line into oncoming traffic	28%	2.0 ± 1.9 (1-6)
Wandered into another lane	28%	3.0 ± 2.9 (0-8)
Arrived at unintended destination	11%	2.5 ± 2.1 (1-4)
Crash, no injury	11%	1.0 ± 0 (1-1)
Crash, with injury	6%	—
Another driver honked	6%	4.0 ± 0 (4-4)
Ran off the road	—	—

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data.

2.3.3.2 Driving Behaviours and Habits

Regarding driving behaviours examined by the DBQ, one-sample *t*-tests show that Phase One participant scores on the DBQ were significantly higher than scores from published Canadian data (Cordazzo et al., 2016), suggesting elevated rates of risky driving behaviours. Higher scores were observed on the Full Scale (*t*(19) = 3.462, *p* = .003) and Distraction and Hurry *t*(19) = 4.958, *p* = <.001). No significant differences were found for Inattention Errors (*t*(19) = 1.911, *p* = 0.071), Age-Related Problems (*t*(19) = .741, *p* = 0.468), nor Aggressive Violations (*t*(19) = 1.941, *p* = 0.067). As shown in *Figure 2-2a*, participants' *z*-scores plotted by subgroup depict a pattern showing that Phase Two eligible participants (versus others) more frequently engage in risky driving behaviours via the Full-Scale score, and subscales Distraction and Hurry, and Aggressive Violations.

Regarding sleep-related driving habits examined by the SFDB, one-sample *t*-tests show that Phase One participant scores on the SFDB were significantly different from data for drivers with normal sleep (Jiang et al., 2017), with elevated levels of Sleepy Driving Behaviour (*t*(19) = 6.83, *p* < .001); Sleepy driving Intent (*t*(19) = 11.666, *p* <.001); Subjective Attitudes (*t*(19) = 2.240, *p* = 0.037); and Subjective Norms (*t*(19) = 2.531, *p* = .02). No significant differences were found for Perceived Behavioural Control (*p* = .442). As shown in *Figure 2-2b*, Phase Two eligible participants (versus other) share similar Subjective Attitudes towards fatigued driving and Perceived Behavioural Control when driving. However, visual trends diverge for Subjective Norms, Fatigued Driving Behaviour and Fatigued Driving Intent, with Phase Two eligible participants endorsing a pattern of elevated scores in these domains.



Notes: ***DBQ subscales:*** *Full = Full Scale score; IE = Inattention Errors; ARP = Age-Related Problems; DH = Distraction and Hurry; AV = Aggressive Violations.* ***SFDB subscales:*** *SA = Subjective Attitudes; SN = Subjective Norms; PBC = Perceived Behavioural Control; SB = Sleepy driving Behaviour; SBI = Sleepy Driving Intent. X̄ = mean, o = outlier.*

Figure 2-2 Boxplots Indicating Driving Behaviour Measures

2.3.3.3 Sleep Quantity and Daytime Sleepiness

Participants' ESS scores (Johns, 1991) were used to quantify daytime sleepiness. Most participants reported daytime sleepiness levels in the Lower or Upper Normal range (45% each), with just 5% each endorsing Mild or Moderate Excessive daytime sleepiness (*Figure 2-3*). Detailed ESS scores (*Table 2-6*), demonstrate a pattern of higher and more variable scores reported by Phase Two eligible participants, (M = 6.1 ± 3.15) than others (M = 3.0 ± 0), suggesting a clinically important difference of 3 points in ESS scores (Patel et al., 2018).

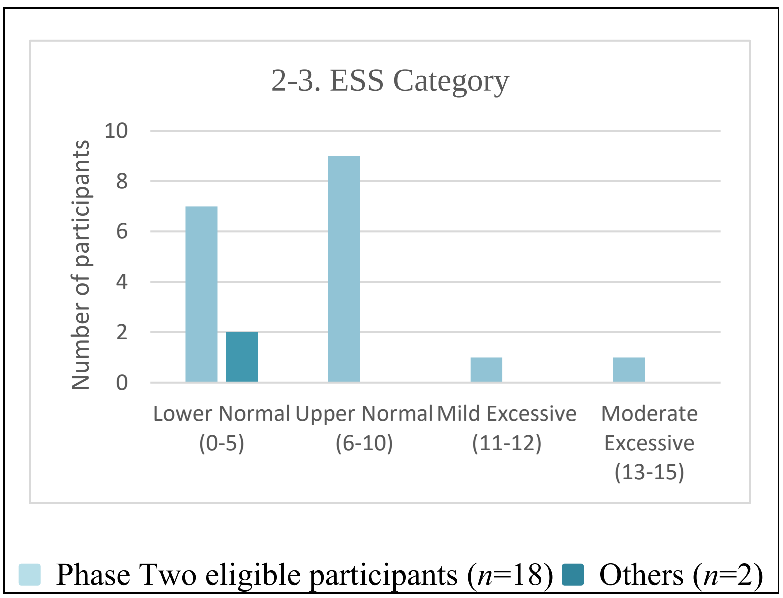


Figure 2-3 Bar Graph Indicating the Epworth Sleepiness Scale (ESS) Category, by group

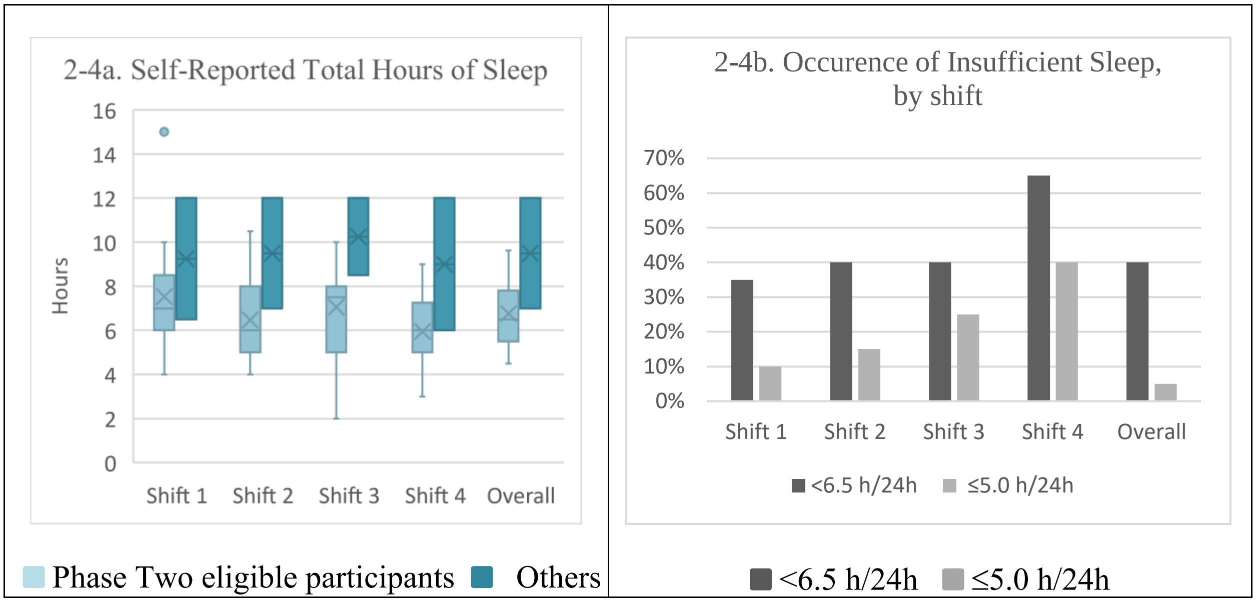
Participants' self-reported total hours of sleep per 24h for each shift (*Table 2-6*), with an overall work-week average of M = 7.05 ± 1.82h/24h (R = 4.5 - 12.0h/24h), with sleep quantity generally decreasing from first to final shift of the week. Phase Two eligible participants show trends of shorter and more variable sleep quantity (*M* = 6.78 ± 1.48h/24h, *R* = 4.5 - 10.1h/24h) compared to others (*M* = 9.5 ± 3.5h/24h, *R* = 7.0 - 12.0h/24h). High inter-individual variability in sleep is demonstrated via response ranges differing by 7.5 to 13.0h/24h, with maximum variability on Shift 3 (*R* = 2.0 - 15.0h/24h), suggesting highly variable sleep habits mid-week when participants transition between day and night shifts. These ranges are graphically depicted in Figure 2-4a.

Table 2-6 Daytime Sleepiness and Sleep Quantity

Sleep Measures	**All Respondents** (N = 20)		**Phase Two Eligible Participants** (*n* = 18)		**Other Participants** (*n* = 2)	
	M ± SD, Percent	*Range*	*M ± SD, Percent*	*Range*	*M ± SD, Percent*	*Range*
Daytime Sleepiness (Epworth Sleepiness Scale)						
ESS Score (0-24)	5.8 ± 3.13	1-13	6.1 ± 3.15	1 - 13	3 ± 0	3 – 3
Sleep quantity (h/24h)						
Shift 1	7.78 ± 2.56	4.0-15.0	7.61 ± 2.47	4.0-15.0	9.25 ± 3.89	6.5-12.0
Shift 2	6.82 ± 2.10	4.0-12.0	6.52 ± 1.80	4.0-11.5	9.50 ± 3.53	7.0-12.0
Shift 3	7.38 ± 2.93	2.0-15.0	7.06 ± 2.86	2.0-5.0	10.25 ± 2.47	8.5-12.0
Shift 4	6.25 ± 2.04	3.0-12.0	5.94 ± 1.63	3.0-9.0	9.0 ± 4.24	6.0-12.0
Overall	7.05 ± 1.82	4.5-12.0	6.78 ± 1.48	4.5-10.1	9.5 ± 3.5	7.0-12.0

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. h/24h = total hours of sleep per 24h, includes both main sleep and any nap(s) taken, summed together. ESS = Epworth Sleepiness Scale (Johns, 1991).

Overall, Phase One participants frequently reported obtaining sleep quantity below the defined cutoff for insufficient sleep (i.e., <6.5 h/24h, suggesting mild insufficient sleep at which cognitive deficits accrue). Figure 2-4b graphically depicts the increase in insufficient sleep from first shift (35%) to final shift (65%) of the workweek, with 20% achieving an overall workweek average in this range. Critically, Phase One participants also reported severely insufficient sleep, at or below the cutoff suggested for impaired driving (i.e., ≤5.0 h/24h)(Dawson et al., 2021), equivalent to alcohol-impaired driving, which increased from first shift (10%) to final shift (40%). Furthermore, 5% achieved a workweek average at or below this cutoff.



<u>Note</u>: Total hours of sleep per 24h (h/24h) includes both main sleep and any nap(s) taken, summed together. Insufficient sleep is defined as <6.5h of total sleep per 24-hour period.

Figure 2-4a and 2-4b Sleep Duration and Occurrence of Insufficient Sleep, by Shift

2.3.4 Phase Two Interview Themes

Thirteen interviews lasting an average of 50 minutes (*R*= 44 – 80 minutes) were completed and analyzed. Four themes were developed overall. Themes one and two highlighted the routine and predictable nature of sleep-related driving experiences (*"It's just kind of expected"*), and participants' sense of altered situational awareness and passive control of driving ("*The car drives itself home")*. Themes three and four focused on the multi-layered, iterative efforts HCSW enacted to limit sleep-related driving events (*"I don't usually let myself get to that point")*, and a lack of formal guidance and resources to support adaptations ("*It's all learn-as-you-go"*).

2.3.4.1 *"It's just kind of expected"* – Routine and Predictable Experiences

Participants described recurrent patterns of sleep-related driving events as routine and predictable consequences of shiftwork, occurring across a range of driving environments and trip durations. Ava (RN) states, *"it's just kind of expected… you have to force yourself awake…[it's] how you feel after working nights… everyone's just in that together."* With experience, participants learned to anticipate whether sleep-related events might occur before getting in the car, based on monitoring their sleep/sleepiness status in relation to the characteristics of their current shift and pending driving demands. Lara (RN) shared that, *"around 5 [AM] I can usually tell – I feel a lot more fatigued, my body hurts…I'm dreading the drive home."* Nightshifts, particularly those with high workloads and/or lacking rest breaks, were often cited as antecedents to sleep-related driving events. Carrie (RN) described, *"I go take a nap on my break. If I don't get that nap… [and] it's been a crazy night, then I know it's gonna be a rough drive home."* Further, shifts occurring late in the workweek, on overtime or late notice for call-in shifts were cited as difficult. Nico (RN) shared, *"it's usually at the end of my stretch [of nights], I find that first drive home doesn't seem to be as severe."* Luke (EMS) described that late notice for call-in shifts made it impossible to adequately prepare for work: *"they call me at 4 pm and [I] gotta be at work at 7 pm… we're not given enough notice to actually sleep before nights."* Together, these findings suggest that an inadequate time to recover from work, the cumulative effect of workweek demands, and/or the inability to prepare for shifts may contribute to sleepy driving events.

Participants described recurrent patterns of sleep-related driving events across all driving environments (e.g., urban to mixed urban/rural drives) and durations as short as 7-8 minutes. While specific examples varied, participants were typically able to identify the patterns of difficulty routinely experienced within their own drives. For example, Ava (RN) noted difficulties throughout her entire urban commute *"probably like 60% of the time [after nightshifts]… and I live like [8 minutes away]",* while Carrie (RN) reported that she would *"prepare for being tired once I get on the highways"* in the latter two-thirds of her mixed urban-rural commute. Likewise, paramedics primarily cited difficulties when working at rural sites, as Allie (EMS) explains *"depending on what base [I'm] working at [city or rural]… that makes a big difference on how tired I am while driving at work."* Sleep-related difficulties were attributed to longer commutes to and from work and on-shift repetitive demands for low-motivation, non-emergency driving. Paramedic participants cited routine provision of standby ambulance support (i.e., backup) to nearby rural municipalities. Allan (EMS) described, "*[standby] drives without the adrenaline rush… it's hard to wake up when you're just going for a drive."* Combined, participant accounts indicate that sleep-related driving events occur in recurrent patterns that shiftworkers learn over time, across a range of driving environments and trip durations.

2.3.4.2 “The car drives itself home” – Driving on Autopilot

Participants perceived their sleep-related driving events to result from an altered situational awareness and cognition, and an impaired ability to recognize and respond to salient cues in the driving environment. These experiences were described similarly across driving environments and trip durations. Participants described feeling absent, dazed, foggy, drunk, or zoned-out. Ramona (RN) describes, “*it feels similar to ‘dissociating’, like not being [present]… just running on autopilot with no conscious thought behind it.”* Nico (RN) described arriving home with no recollection of his urban commute, feeling like he was driven by the car. He described this as a common phenomenon discussed amongst his co-workers: *“You arrive at home, and you have no idea how the car got there. And you wonder – ‘Did the car do that by itself?’ You know that it’s not capable, but it’s a joke we share with each other.”*

When experiencing sleepiness, participants indicated difficulty with regulating focus and attention on cues in the driving environment which resulted in a sudden-onset awareness of route location, missed intended turns/stops, striking a car when parking, or an inappropriate response to traffic controls. Carrie (RN) described: *“I’ll pull up to a red light… look both ways and I’ll just drive through it because I’m not paying attention, and I’m like ‘Oh my God! That was a light! That was not a stop sign!”* Kira (RN) described: *“I was so tired… I was so focused on the road, I did not see the light turn red, and I just like blew right through it… thankfully nothing happened, but it was red for a good long time.*” Like Kira, other participants expressed gratitude that they had averted serious implications of these sleep-related driving events to date, such as, *“thank goodness it’s such a short drive”* (Nico, RN). Such sentiment underscores the degree of subjective difficulty experienced, and awareness of the potential for serious outcomes.

2.3.4.3 *“I usually don’t let myself get to that point”* – Iterative Efforts to Reduce Sleep-Related Driving events

Participants employed multiple layers of occupational adaptations over varying timeframes and contexts to limit sleep-related driving events. These layers included: (1) proactively avoiding circumstances related to prior sleepy driving experiences; (2) planning ahead of shift(s); (3) preparing on-shift; and finally, (4) increasing alertness when driving to push through to their destination.

Proactively altering driving demands. Throughout their career, participants engaged in macro-level strategic decision-making to adjust their long-term driving demands related to where to live or work, and when and/or how much to work. To mitigate their risk of future sleep-related driving events, participants considered their prior sleep-related driving events and associated antecedents and sought to avoid replicating such circumstances. These strategic macro-level decisions typically resulted in reducing overtime or nightshifts, leaving small-town or rural workplaces, and/or reducing exposure to rural environments, complex demands, or longer commutes. For example, Nico (RN) shared how one sleep-related driving event led him to quit working a casual overtime position at a small-down workplace requiring a longer commute:

> *"One morning… I snapped awake…was in a totally different lane on the [highway]… it's one of those episodes where you start to question: 'Am I doing the right thing working these extra shifts... commuting back and forth?'… Shortly thereafter, I actually stopped doing the extra shifts because of that episode."*

As another example, Kira (RN) reported resigning from shiftwork entirely to seek dayshift work, citing persistent sleep-related driving events after nights: "It's *kind of pushing me away from nights, like I just don't want to do them anymore… I can barely make it home."*

Planning ahead of shift. Participants planned their scheduled workweek to manage their sleep/sleepiness and mitigate sleep-related driving events through using their preferred self-care routines, and/or temporarily modifying work or driving demands. However, participants experienced multiple barriers to planning and implementing plans, reducing effectiveness. Participants developed preferred self-care routines with shiftwork experience, consistently focusing on scheduled sleep/nap times, sleep-hygiene strategies, with occasional focus on nutrition, exercise, and/or sleep-aid supplements. Additionally, participants considered temporarily altering their workweek demands via reducing their driving (e.g., carpool, transit) or work schedule (e.g., trading shifts). Carrie (RN) adapted her schedule by, *"trad[ing] out one nightshift so that I don't have to do two in a row… I find I don't sleep well between nights… [but] I can make it through one."*

Despite self-care strategies, participants experienced multiple barriers such as logistical or geographical constraints, unpredictable work-life demands, and unpredictable schedules that impeded their planning or implementation of self-care. For example, carpooling or trading shifts depended on finding a willing co-worker with the same work and commuting schedule. Accessing public transit was geographically constrained, and schedules ill-suited for weekend or nightshifts. Unpredictable work-life demands had a lasting impact on sleep, as Allan (EMS) describes: *"life happens… If I'm between my nightshifts… all it takes is one interruption of that sleep [routine] and then I'm in trouble for the next 2-3 days."* Likewise, call-in or overtime shifts were often unpredictable, with inadequate notice to plan workweek demands or implement self-care strategies. Luke (EMS) shared, *"part-time [employees], odds are you can't prepare for a nightshift…just have to say yes to everything... [7 to] 8 out of 10 shifts are all last minute… [I'll] sleep when I'm dead, I guess, right?"* Critically, the latter barrier was shown predominantly in new-graduate or part-time employees working towards obtaining a full-time job — which may persist for several years. Despite well-intentioned efforts to mitigate sleep-related driving events, some participants unwittingly employed ineffective strategies that may increase their risk, such as forgoing or severely restricting sleep before the first nightshift to become 'tired enough' to sleep between subsequent nightshifts. While participants planned for and attempted to implement a variety of strategies to manage sleep/sleepiness and mitigate sleep-related driving events, it is evident that their attempts were limited by multiple systemic barriers.

Preparing on-shift. When working, participants monitored and self-managed their sleep/sleepiness by using breaks to eat, rest, or nap, and promote alertness for their pending driving demands. Nico (RN), stated: *"it's kind of an unspoken secret [of shiftwork]… In order to function and be able to get through an entire shift, you'd better care for your brain and get some form of rest somewhere."* Some units self-described as 'napping units', supported napping on break, *"on my unit, sleep breaks are a real thing… we endeavour to cover each other to get good blocks of sleep [or rest] (Nico, RN)."* Yet, this strategy to support the team to nap on break was rarely discussed outside of the unit, due to perceived institutional restrictions –"*we don't flaunt it" (Lara, RN).* For paramedics, breaks for self-management involved rotating from driver to passenger to rest and eat. Allan (EMS) describes preparing on-shift to avoid sleepiness when driving, *"I usually don't let myself get to that point… I'm very self-aware of my fatigue level... [I] tell my partner 'You're gonna have to drive tonight'… [I] have a coffee… grab a bite to eat* *so I can get my energy level back up."* Regardless of how breaks were utilized, participants noted experiencing increased difficulty in the subsequent drive if they could not take a meaningful break within their 12h shift. Barriers to consistent breaks were pervasive and varied by unit for access, scheduling and length, team support, and perceived or actual institutional policy restrictions on permissible break activity. Kira (RN) described having difficulty upon moving to a new job, describing, "*It's just no breaks… [in my old job, I could] shut my eyes for a few minutes, it [was] a whole different story… [but in this job] it's just the mentality that nobody takes a break… and nobody knows why."* Monitoring sleep/sleepiness levels enabled participants to enact strategies to increase alertness immediately before embarking on a drive at the end of shift. Ramona (RN) shared, *"If I'm feeling super sleepy at work before I leave, I'll … have a good conversation with somebody or try to do something that will wake me up a little … before I have to drive home."*

Increasing alertness and pushing through sleepiness to drive. Finally, while driving, participants focused on increasing alertness. Rarely stopping, participants primarily pushed themselves to continue driving to their destination while attempting to increase alertness and reduce sleepiness through activities (e.g., eat, drink, chew gum, sing) or through interacting with vehicle equipment (e.g., increase music volume, cold airflow). Intermittently, participants used phone calls to enhance alertness when recognizing patterns related to prior sleep-related driving events (e.g., highway, later in drive, high levels of sleepiness). Less frequently, participants modified speed or following distance via: (1) reducing speed or increasing following distance, citing hypervigilant awareness of altered mental state, or (2) increasing speed to enhance alertness or arrive to the destination more quickly.

The tendency to "push through" is evidenced by participants rarely stopping to take a break while driving, unless experiencing severe sleepiness or having already fallen asleep. Instead, some participants indicated relying on physical features of the driving environment (e.g., rumble strips on the highway shoulder) as a backstop to temporarily increase alertness. Luke (EMS) shares, *"when you hit the rumble strip… it jolts you awake… an adrenaline rush… if you're dead tired, then that's what you need."* Yet, effects waned over time with repeated use, Kira (RN) states, *"even the rumble strip hasn't really woken me up that much… I've woken up on the other side of it before… I already went over it." (Kira, RN).*

Despite reporting sleep-related driving events, participants remained confident in their driving abilities, citing their past experiences driving under a variety of states (i.e., alert to sleepy), Allie (EMS) shared, *"over time… I've become more comfortable with driving, so I'm kind of able to push… things a little bit further."* Participants indicated developing a tendency to 'push things', thus avoiding stopping wherever possible in order to get home more quickly. Luke (EMS) shared, "*I just gotta get home…I feel like maybe … subconsciously that I'm really not that far from home. Although you know half an hour is still a good distance if you're tired."* Combined, these factors paint a troubling picture with contradicting thoughts and actions: participants indicate greater confidence in their driving ability over time, yet, acknowledge they are 'pushing' their limit and may engage in driving behaviours that increase risk (e.g., increased speed, a distraction from phone calls), and relying on features of the external driving environment (e.g., rumble strips) to alert them, despite the reactive, temporary, and waning effect of such features.

2.3.4.4 *"It's all learn-as-you-go"* – Experiential Learning with Limited Guidance

Participants indicated little-to-no formal education or resources related to navigating shiftwork, managing sleep and sleepiness, or mitigating sleep-related driving events. Instead, participants relied on learning through their experiences, from their co-workers and/or preceptors, and often cited employers and workplace policies as posing barriers.

Sleep-related content in curriculum or workplace orientation was limited to brief patient-centered information (e.g., delirium, avoid waking patients), while employee-centered information was rarely cited or informative (e.g., nil information to a single slide on sleep-hygiene tips in a wellness webinar). Workplace orientation focused only on required basic work procedures, as Lynn (RN) recalls, *"they barely give us education on the unit we're actually working…it's all 'learn as you go."* Instead, participants learned occupational adaptations via informal means, including following established workplace/unit norms around break structure and use; explicitly asking more experienced co-workers or preceptors for strategies; general discussions with co-workers; and reflecting on their personal experience to identify which adaptations were helpful and when. Specifically, new graduates referenced learning from preceptors and mentors, while all new staff suggested observing and following established workplace norms and followed similar strategies. For example, Kira (RN) shared, *"I'm one of the newer nurses…whatever they* *follow, then I follow that also."* Carrie (RN) reflected on a supportive workplace culture modelled by her preceptor, *"when I was young…everyone…[laid] down and I think that's why I got into sleeping…all of them would close their eyes…my preceptor did, then I would too."* Conversely, Ava (RN) shared difficulties in adapting and taking breaks, *"it's hard being [new] …I didn't really know anyone, I wouldn't really ask anyone to cover my patients [so I could have a break.]"* This variable approach to unit culture was evident in its impact on occupational adaptations.

Predominantly, the employers, management, and policies were viewed as presenting barriers to participants, and few resources existed to support shiftworkers. This resulted in participants subverting (un)written policies to cope, and unable to access resources. Allan (EMS) lamented, *"the biggest complaint I hear is that management doesn't care if we're dog tired,"* while Ava (RN) stated, *"I wish I could say that the [employer] has helped to make options available to shiftworkers."* (Un)written policies and/or perceived management opinions were cited as barriers to enacting preferred coping strategies like napping during a break, Nico (RN) stated that napping on breaks was *"frowned upon...[but] there's nothing [that]…actually says it's against the rules or against the policy…[management] do endeavor to make it as difficult as possible."* Thus, participants adapted by not speaking about napping outside of their unit (Lara, RN: "*we don't flaunt it")*, or making naps appear unintentional to avoid potential discipline (Allan, EMS: "*if you fall asleep in a recliner, you hope that the supervisor doesn't come in…do not have a blanket on, don't have your [footwear] off, don't have [the room] dark.")*

Further, participants were either unsure if workplace resources existed, or, how to access them if they did. Lynn (RN) shared this uncertainty as to who would be responsible for any resources, *"I don't know if it's a union thing, or a management thing…I've heard rumblings."* One potential resource was using a taxi chit to get home after an overtime shift; however, access procedures rendered this unattainable. Nico (RN) shared: *"I've never seen anybody take it…it isn't that we don't choose to… we have to jump through a couple of hoops [to get permission]…who really wants to do all that work? It was so much easier just to drive home."*

Together, shiftworkers are neither informed on their need for sleep nor effective means by which to manage their sleep/sleepiness. Further, they are disempowered in their efforts to manage their sleep and sleepiness using evidence-based strategies (e.g., naps on breaks) due to fear of reprisal; and lack of awareness and reasonable procedures to obtain resources (e.g., pre-paid taxi chit, where offered).

2.4 Discussion

The aim of this mixed-methods study was first, to quantify HCSWs' driving history, habits, behaviours, and sleep and sleepiness; and second, to advance the understanding of HCSWs' sleep-related driving experiences, and contextual factors influencing adaptations related to driving. These objectives were achieved via a two-phase multiple-methods study, comprised of an online survey (quantitative) and one-to-one interviews (qualitative). Twenty online surveys were completed by nurses and paramedics, who were majority female (80%) and ranged in age from 21-58 years (*Mdn* = 29.5 years), and in shiftwork experience from 1-36 years (*Mdn* = 7.5 years). Eighteen HCSW (90%) experienced sleep-related driving events in the past year, and were eligible for the one-to-one interview, with 13 interviews completed.

Phase One survey findings show multiple data trends with practical implications. Overall, 90% of survey participants reported a 1-year driving history with severe sleepiness, 40% nodded off, and 20% fell asleep while driving. Similarly, the most-frequently reported adverse driving events included startling awake in the same lane (78%) and memory gaps for the preceding few kilometers (67%). Overall, participants reported significantly elevated risky driving behaviours (e.g., overall, distraction and hurry errors) and sleep-related driving (e.g., behaviour, intent, perceived positive attitude and peer norms) compared to relevant normative data. Sleep data trends suggest that insufficient sleep is common amongst HCSW and increased in frequency and severity throughout the workweek, with 40% reporting <5h/24h sleep on their final shift. Together, these data trends suggest HCSW are an at-risk group, via elevated rates of sleep-related and adverse driving events, risky and sleep-related driving behaviours, and insufficient sleep.

Examining subgroups, Phase Two eligible participants (*n* = 18) reported a 1-month history of driving with severe sleepiness (94%, *M* = 5 episodes), nodding off (28%, *M* = 1 episode), or falling asleep (11%, *M* = 2.5 episodes). Moreover, Phase Two eligible participants with a 1-year history of sleep-related driving events (versus others with no such history) showed trends towards further elevated risky- and sleep-related driving behaviours, more frequently continuing to drive after noticing sleepiness, shorter and more variable sleep quantity, and higher levels of daytime sleepiness.

Phase Two interview findings highlight four themes. Two focused on the driving experiences and perceptions, and two focused on adaptations enacted and the experiential learning and supports used to learn and implement adaptations. HCSW described their experiences of sleep-related driving events being routine and predictable consequences of nightshift work, occurring in recurrent work- and/or driving-related patterns. HCSW reported driving while experiencing altered situational awareness and cognition, and difficulty recognizing and responding to salient environmental cues, as if driving on autopilot.

HCSW reported multiple occupational adaptations described as ongoing and multi-layered efforts to mitigate sleep-related driving events over varying timescales. Yet, despite these recurring adaptations to mitigate risk, 90% of HCSW reported at least one sleep-related driving event in the past year. These occupational adaptations heavily focused on pre-driving adaptations (e.g., strategic driving behaviours) ranging from modifying work and driving demands long-term (e.g., years) to short term (e.g., weekly or daily demands), and self-manage sleep(iness) before and during shifts to avoid antecedents to prior sleep-related driving events. Finally, after multiple iterations of strategic-level adaptations, HCSW focused on implementing in-vehicle adaptations to increase alertness to drive to their destination.

Currently, research primarily focuses on how drivers use countermeasures to address acute sleepiness while driving (e.g., continue to drive using in-vehicle adaptations primarily at the tactical or operational level driving behaviours, versus stopping or modifying driving using strategic level driving behaviours). However, findings in this study suggest a critical gap between the existing research foci and the range of occupational adaptations reported by HCSW. Specifically, adaptations reported by HCSW heavily focused on strategic pre-driving adaptations to proactively avoid, plan ahead, or prepare-on shift to mitigate the risk of acute sleepiness occurring while driving or to reduce its impact once it occurred. This change in research focus may be most pertinent to drivers who are routinely exposed to conditions that increase the risk for sleep-related driving events, like shiftwork, compared to general drivers. Therefore, research focusing on higher-risk groups for sleep-related driving events may consider examining a broader a range of pre-driving adaptations at the strategic level of driving behaviour.

Per Michon's Model of Driving Behaviour (Michon, 1985), the strategic level of driving behaviour involves planning and/or modifying driving routes based on anticipated short-term or current road and/or driver conditions (e.g., modifying route due to weather or construction, or changing plans due to driver status). However, findings in this study suggest a gap, where higher-order strategic behaviours focus on medium-to-long-term to planning and/or modifying driving demands, routes, and conditions to adapt to driver capacity considering prior sleep-related or adverse driving experiences. Such higher-order driving behaviours and conditions are not captured by this current definition, and may warrant exploring a higher-order term, such as the 'macro-level strategic' driving behaviour. A macro-level strategic driving behaviour category may more accurately capture: (1) the higher level of cognition (e.g., self-awareness, reflection, complex work-life decisions); (2) longer timeframes required to reflect on the sleep-related driving experience and enact adaptation(s); and (3) the long-term impact of such decisions (e.g., (semi)permanent changes to driving demands via changing commute).

Accordingly, *Figure 2-5* illustrates conceptually how the themes of occupational adaptations arising in this study (numbered 1 through 4 on the figure) can align with, and expand upon, Michon's Model of Driving Behaviour (Michon, 1985). Progressing from bottom-up, the expanded concept of 'macro-level' strategic driving behaviour forms the foundation upon which the remaining levels of occupational adaptations are enacted and aligns (1) Proactively altering driving demands long-term via choosing/changing work and home locations to structure commute and work demands. Next, the strategic level of driving behaviour encompasses anticipated short-term and current driving demands via (2) planning ahead of shift and (3) preparing on-shift to modify/manage driving demands (e.g., trade shifts or carpool) and/or driver capability (e.g., manage sleep and sleepiness levels prior to driving). Finally, tactical and operational levels of driving behaviour are primarily represented in (4) increasing alertness and pushing through driving, with a focus on increasing driver alertness (e.g., air flow, music, food, talking), or altering driving (e.g., increasing or decreasing speed), with minor instances of strategic behaviour (e.g., planning a stop or phone all mid-commute to complete an errand and increase alertness).

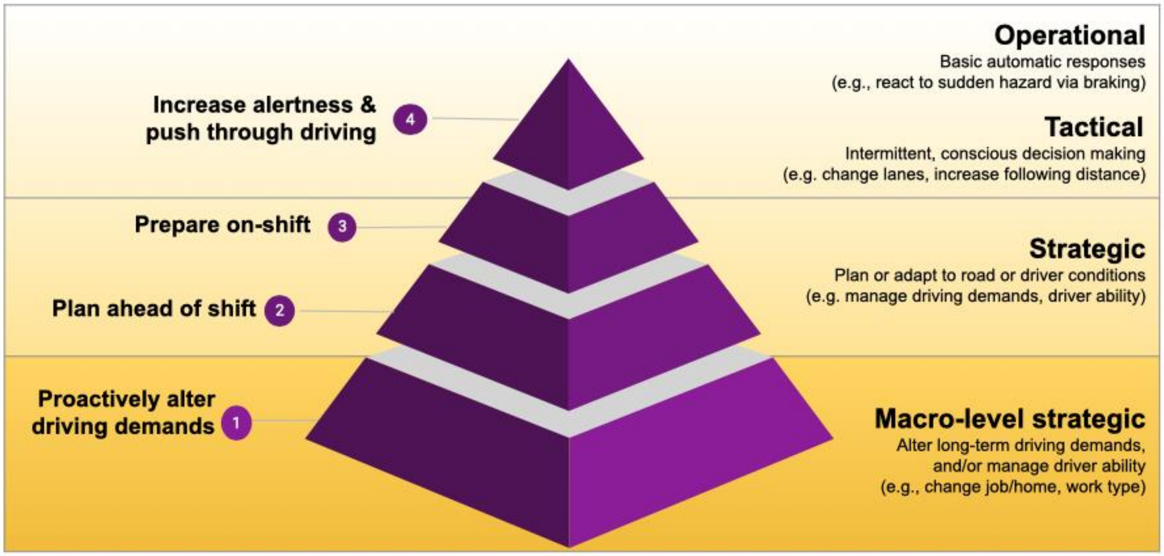


Figure 2-5 Occupational Adaptations Contextualized via Driving Behaviour Model (Michon, 1985), and Proposed Macro-Level Strategic Driving Behaviour

Finally, HCSW cited barriers to learning and/or implementing adaptations via a lack of education and/or resources, combined with multiple systemic barriers. Specifically, a lack of formal education on sleep (e.g., school, workplace) resulted in relying on experiential or informal learning from colleagues. These findings are consistent with existing research citing gaps in healthcare worker curriculum on sleep knowledge for both clinical and self-management skills (Meaklim et al., 2020), thus relying on learning from personal or coworker experience (Smith et al., 2019).

A lack of education on the biological necessity for sleep and the effects of insufficient sleep may inform beliefs that one can skip sleep with little consequence, resulting in inadvertently using adaptations that increase their risk of sleep-related or adverse driving events. For example, several HCSW cited remaining awake for >24h between day and night shifts in order to become ‘tired enough’ to sleep between subsequent night shifts, or, not wanting to ‘waste’ a day off sleeping, and instead waking early to run errands – both of which can result in driving impaired by insufficient sleep. Indeed, findings from this study suggest that 40% of HCSW obtain below the 5h/24h sleep cut-off on the final shift of the workweek. Further, cognitive deficits in multiple areas arising from insufficient sleep, combined with speeding up to get home, and/or pushing through sleepiness and avoiding stopping, are counterproductive as they serve to increase the cognitive demands of driving at a time when the driver is less capable of handling such demands.

Further, a lack of resources and multiple systemic barriers were reported (e.g., unpredictable scheduling, variable unit/workplace culture and physical environment, and unclear policy/rules). Combined, these barriers currently perpetuate the occupational deprivation of sleep in HCSW (e.g., where HCSW are limited in their ability to sleep due to the context of shiftwork employment, with little individual control) (Leive & Morrison, 2020). These barriers also perpetuate a restricted range of occupational possibilities. Recalling that occupational adaptations are derived from occupational possibilities (Laliberte Rudman, 2010), restricting the range of occupational possibilities in turn limits the occupational adaptations that HCSW can practically implement to manage driving demands and sleep and sleepiness in the context of shiftwork. These contextual factors and systemic barriers suggest a disproportionate impact on the youngest HCSW, who, in addition to lacking formal education, resources, and systemic barriers, are an at-risk population of drivers arising from less driving experience and a greater vulnerability to insufficient sleep.

2.4.1 Limitations

This mixed-methods study was designed to ensure an adequate sample size for the one-to-one interviews. Thus, the survey was neither intended to, nor adequately powered for generalizing to the entire Canadian healthcare workforce nor to compute inferential statistics for sub-group analyses. Participant recruitment for the Phase One survey relied on convenience sampling, thus, it is possible that participants with more significant history or passionate responses were drawn to participate from the overall population of HCSW. Finally, interviews were conducted only with HCSW who reported at least one sleep-related driving event in the past year; and it is possible that the driving experiences and adaptations used to navigate driving demands in the context of sleepiness may differ in HCSW without a recent sleep-related driving history and inform a need for future research. Transferability of interview findings should be informed according to the context of the study participants (e.g., healthy nurses and paramedics) and setting (e.g., employed in the publicly-funded healthcare employers in small to mid-size cities in Ontario, Canada, during the first year of the COVID-19 pandemic).

2.4.2 Strengths

Employing a mixed-methods approach to examine HCSWs' sleep-related driving experiences, habits, and adaptions enables multiple data points to provide complementary information a multi-dimensional understanding of the research question (Creswell, 2014; Creswell et al., 2011). The participants in this study were representative of those employed in the healthcare sector, being majority female (80%), with a wide range of age (21-56 years) and shiftwork experience (1-36 years), and included those who work both full-time or full-time equivalent between one or more roles. This wide range of age, length and type of shiftwork experience enabled a diverse set of perspectives on sleep-related driving experiences. Participants for the Phase Two interviews were selected using purposive sampling to target a homogeneous participant group with relevant lived experience pertaining to sleepy-driving and/or adverse driving experiences, which may enhance the richness of data obtained (Braun & Clarke, 2013). Finally, an established six-phase inductive thematic analysis approach was used (Braun & Clarke, 2006, 2012, 2013) and this manuscript followed the MMARS reporting guidelines (Levitt et al., 2018).

2.4.3 Implications

Findings from this study have implications for future research on HCSW driving performance and driver behaviour theory, healthcare worker education, and institutional policy.

Future research should identify whether the patterns and trends in HCSW's sleep-related and adverse driving events, risky and sleep-related driving behaviours, driving habits, and sleep and sleepiness differ significantly from healthcare workers who work regular day shifts. Further, HCSW cited experiencing alterations in awareness of, and ability to react to, salient cues in the driving environment (e.g., mistaking stop light for a stop sign). Future research may further examine this claim via instrumented vehicle studies with videotape recordings that could be evaluated by a trained driving evaluator to examine behaviours associated with scanning, perceiving, and responding to cues in the environment (e.g., appropriately scanning for environmental hazards, appropriately adjusting driving behaviour to adapt to traffic flow). Additional qualitative research may build on the interview findings in this study by including HCSW without a 1-year driving history for sleep-related driving events, to triangulate data with the findings from this study to examine areas of convergence or divergence related to driving experiences, adaptations, and context (Farmer et al., 2006). Combined, such data may aid in identifying and tailoring interventions to address key areas of driving performance. Finally, future in driving behaviour theory may build on the findings of adaptations reported by HCSW to further examine and/or develop a theoretical body of literature to validate expanding theoretical constructs of strategic, operational, and tactical levels of driving behaviour to also include the concept of 'macro-level' strategic driving behaviour.

Implications for education arise from an apparent lack of formal education for HCSW (e.g., via curriculum, workplace training, professional development) on sleep and the negative effects of insufficient sleep limiting HCSWs' ability to enact evidence-informed occupational adaptations. Further, published research and professional association recommendation include calls to formalize education on sleep and the translation of evidence-based practices (Canadian Nurses Association, 2010; Meaklim et al., 2020), as well as recognizing and mitigating the risk of sleep-related driving events through pre-driving adaptations (Thomas et al., 2021). Adapting formal curriculum to include sleep and the impacts of insufficient sleep will enable new graduates to begin their career with evidence-informed strategies, while continued professional development will enhance awareness among preceptors and supervisors to aid in the successful implementation of policies and practices (Geiger-Brown et al., 2016; Sprajcer et al., 2022).

However, providing education to individual HCSW without reviewing the systemic barriers in resources, supports, and institutional policy only serves to perpetuate an individualistic approach to a systemic problem. Therefore, a focus on policy is required to address the impact of shiftwork on sleep(iness), driving, and other pertinent areas outside of the scope of this paper (e.g., patient care, employee health, etc.) (Canadian Nurses Association, 2010). Specifically, our findings reinforce the need for institutional policies to recognize the essential nature of sleep, the impacts of insufficient sleep, and share responsibility in mitigating these impacts on HCSW health and function (Sprajcer et al., 2022). Multiple aims of policy implications may include scheduling to allow sufficient rest and preparation, enabling HCSW to access regular breaks with quiet areas where they are permitted to sleep or rest as needed, and establish a supportive workplace culture (Canadian Nurses Association, 2010). For example, multiple studies have found that napping during regularly scheduled breaks is an evidence-based strategy to improve sleep quantity and psychomotor vigilance, reduce sleepiness during shifts and driving home, enhance productivity and overall performance, and aid in post-shift recovery (Geiger-Brown et al., 2016; Li et al., 2019; Sun et al., 2019). Despite such evidence and the Canadian Nurses Association (2010) supporting explicit policy to allow rest or naps on breaks, most HCSW perceived napping was against policy, and subject to reprimand.

Further, an institutional policy may also focus on clearly communicating resources and reducing access barriers to encourage HCSW to modify or reduce driving demands, either on a routine basis or when they perceive they are unsafe to drive home. HCSW reported considering alternatives such as carpooling, public transit, or a rideshare/taxi chit; however, multiple barriers limited access (e.g., geography, scheduling, social knowledge of a partner to share with, onerous rules for taxi-chit approvals). However, emerging data suggest that removing barriers to alternative transportation options may reduce sleep-related driving events at a modest cost. White et al (2021) examined the impact of an employer-paid, optional ride-share program (e.g., Uber) for employees perceiving they are unsafe to drive home post-shift. This 8-week trial incurred only modest costs, with 16.6% of participants using the rideshare at least once, predominantly young residents or those with long commutes, and significantly reduced the occurrence of nodding off or falling asleep (White et al., 2021). Such actions may empower HCSW to implement strategic driving adaptations and modify or reduce driving demands and improve driving outcomes.

2.5 Conclusions

This study quantified HCSWs' sleep-related driving history, habits and behaviours; and advanced the understanding of HCSWs' sleep-related driving experiences, adaptations, and contexts factors influencing adaptations related to driving. Findings show that HCSW are an at-risk population of drivers, with 65% obtaining insufficient sleep (<6.5h/24h) and 40% obtaining severely insufficient sleep (≤5.0h/24h) at least once weekly. These results suggest that up to 40% of HCSW may drive impaired by insufficient sleep (equivalent to alcohol impairment) on a weekly basis (Dawson et al., 2021). Further, HCSW reported a 1-year driving history significant for sleep-related events including: severe sleepiness (90%), nodding off (40%), or falling asleep (12%). Such driving outcomes were described as both routine and predictable consequences of shiftwork, despite multiple layers of adaptations in place to proactively avoid, plan, and prepare on shift to mitigate the occurrence of sleep-related driving events. HCSW cite heavily relying on pre-driving adaptations at the strategic and macro-level strategic level of driving behaviour, which may have important implications on driver behaviour theory and research. Critically, HCSW face multiple systemic barriers limiting the occupational possibilities and adaptations they can implement to manage sleep(iness) and driving demands in the context of shiftwork, and evidence-based coping strategies. Further, multiple systemic barriers impact HCSWs' ability to plan for work or enact plans before or during shifts, and with little or no training and resources to support these adaptations using evidence-informed approaches. The occupational deprivation of sleep, and increased risks associated with driving performance highlight important implications in healthcare provider education (e.g., curriculum, professional development), and institutional policy (e.g., workplace safety and training, scheduling, policy governing breaktime use).

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Chapter 3

3 Sleep, Sleepiness, and Driving Performance in Healthcare Shiftworkers[1]

A survey of Canadian drivers shows that 58% of drivers experience sleepy driving, with 14.5% reporting either nodding off or falling asleep while driving (Vanlaar et al., 2008). However, data on nurses working night shifts suggests that 67% and 80% reported sleepy driving and up to 95% reported experiencing adverse driving events, such as missing turns, falling asleep while driving, or highway hypnosis (i.e., memory gaps for parts of the drive), most often on the drive home from work after an extended period of wakefulness (Mulhull et al., 2019; Novak & Auvil-Novak, 1996; Scott et al., 2007). This sharp contrast in the prevalence of sleep-related driving events between the general population and night shift working nurses highlights the need to examine differences in in sleep, sleepiness, and driving performance in this potentially at-risk group of drivers. Moreover, the demands of shiftwork in healthcare are pervasive. While just 28% of Canadians are shiftworkers, in healthcare this rises to 45% overall, with certain occupations (e.g., paramedics) exceeding 80% shiftwork employment (Fischer & MacPhee, 2017; Williams, 2008). Shiftwork involves working non-standard hours (e.g., outside of 9:00 am – 5:00 pm), such as afternoon or overnight shifts (Cheng & Drake, 2016), with 12h day/night rotating shifts (e.g., 7:00 am-7:00 pm) commonly used. As such, those working shifts may be required to work and sleep at times outside of their natural circadian rhythm (i.e., predictable daily peaks and troughs in alertness) and endure extended periods of wakefulness, resulting in high subjective sleepiness, and poor sleep quality and quantity (Akerstedt & Wright, 2009).

While adults require 7h to 8h sleep per day (i.e., 7-8h/24h) to maintain stable neurobehavioural and neurocognitive functions (Banks et al., 2017), impairments in neurobehavioural and neurocognitive deficits may occur with <6.5h/24h sleep. Resulting deficits such as slowed reaction times and information processing, hypovigilance, impaired memory, and divided, selective, and sustained attention have a negative impact on driving (Banks et al., 2017; Barco et al., 2012; Basner et al., 2013; Bonnet, 2011; Czeisler et al., 2016; Goel et al., 2009; MacLean,

[1] A version of this manuscript is in preparation for submission to the journal *Sleep.*

2016; Watson et al., 2015). Critically, healthcare shiftworkers on rotating 12h day/night shifts have been found to obtain just 5.4-5.7h/24h throughout the workweek, and 45% report high subjective sleepiness peaking at the end of each shift and at the end of each week (Geiger-Brown et al., 2012). Furthermore, a recent systematic review found that overnight shiftwork and subjective sleepiness were *likely* and *possible* predictors of adverse driving outcomes, respectively (Knott et al., 2020). However, insufficient evidence was found on the impact of 12h rotating day/night shifts which is commonly required in healthcare settings (Knott et al., 2020). Moreover, healthcare worker samples other than physicians were under-represented in research studies (e.g., nurses, paramedics), along with women and younger workers (Knott et al., 2020).

Driving performance is comprised of five primary components, including: (1) *driving history*, including the driving record, education, licensing; (2) *driving habits*, such as good or bad driving practices repeated over time; (3) *driving behaviours*, such as strategic, tactical and operational level behaviours for vehicle control; (4) *driving abilities,* comprising the neurocognitive or neurobehavioural or sensory-perceptual skills required to control a vehicle, and (5) *driving skills*, comprising knowledge of traffic rules and demonstrated vehicle control decisions, typically at the operational or tactical level behaviours during a driving simulator assessment (Classen et al., 2017; Michon, 1985; Transportation Research Board, 2016). Data suggests that healthcare SW may be an at-risk group of drivers due to experiencing insufficient sleep and elevated levels of sleepiness, and are at risk for impaired cognitive driving abilities secondary to insufficient sleep. Further, survey data suggest elevated occurrence of sleep-related or adverse driving events, and a systematic review concludes that working overnight shifts and high subjective sleepiness likely and possibly predict adverse driving outcomes. Yet, little is known in terms of healthcare SW's overall driving performance including history, habits, behaviours, abilities, and skills.

To date, research on SW driving performance focuses on driving simulator or closed-track in-vehicle studies, employing low-complexity and monotonous highway driving environments. These environments are used to elicit signs of sleepiness, and outcome measures primarily focus on a narrow spectrum of driving performance (e.g., standard deviation of lateral position or speed) (Knott et al., 2020). While such information provides foundational knowledge of operational-level driving behaviours (e.g., interacting with steering wheel or brake to modulate speed or positioning), little is known on driving performance in more complex driving environments (e.g., urban/suburban) representative of real-world driving that may demand higher tactical or strategic level behaviours required to adapt to the flow of traffic) (Knott et al., 2020; Michon, 1985). Such research is critically needed to inform understanding of real-world driving in complex environments and conditions faced by shiftworkers in their daily driving demands (Knott et al., 2020).

Several naturalistic driving studies have examined subjective and objective measures of sleepiness, along with self-reported adverse driving events experienced by healthcare SW during typical commutes using their own vehicle. These studies used within-subjects designs to examine differences in pre-shift and post-shift drives in permanent night SW nurses (Ftouni et al., 2013), resident physicians working >24h shifts and regular day shifts (Anderson et al., 2018), and nurses working rotating day, evening and afternoon shifts (Mulhull et al., 2019). These studies identified increased objected and subjective measures of sleepiness, and significantly increased sleep-related (e.g., nodding off), inattention (e.g., distraction), and hazardous driving events (e.g., errors), with no differences in violations (e.g., crashes, near-misses). While these studies examine driving performance in real-world driving environments and conditions experienced by healthcare workers, within-subjects designs are unable to quantify whether the occurrences of such sleep-related or adverse driving events may differ from a non-shiftworker population.

This study aims to build on the current literature by directly comparing the sleep, sleepiness, and driving performance outcomes in healthcare workers working 12h rotating day/night shifts, versus healthcare workers who work regular day shifts. Further, driving performance will be conceptualized broadly to include driving history, habits, behaviours, abilities, and events. This study was conducted during the COVID-19 pandemic restrictions, and as such, driving skills could not be directly evaluated via a driving simulator or in-vehicle driving study. Instead, driving events were examined in naturalistic driving environments encountered by healthcare workers in their usual daily driving demands (e.g., include urban, suburban, highway or rural environments) for commuting and other daily driving demands, using daily driving logs validated in prior research (Anderson et al., 2018; Ftouni et al., 2013; Mulhull et al., 2019).

3.1.1 Objective

In healthcare shiftworkers on a 12h rotating day/night shifts (SW) versus healthcare dayworkers working regular day shifts (DW), determine what differences exist in: (1) self-reported and objective measures of sleep quantity and quality, and self-reported sleepiness levels over a 14-day period; and (2) self-reported and proxy-rated driving performance, comprised of measures in self-reported driving history, driving habits, driving behaviours, objective assessment of cognitive skills underlying driving abilities, and self-reported driving events documented in twice-daily driving logs over a 14-day period and at a 1-month follow-up survey.

3.1.2 Hypothesis

Overall, we hypothesized that there would be significant between-groups differences in sleep, sleepiness, and driving performance outcomes. Specifically, we hypothesized that SW would demonstrate: (1) poorer sleep quality and quantity, and increased sleepiness; (2) higher frequency of sleep-related and adverse driving events, citations or infractions; elevated levels of self-reported risky driving behaviours and sleep-related driving habits; lower ratings on proxy-rated safe driving behaviour; and poorer performance on cognitive screening.

3.2 Methods

The Health Sciences Research Ethics Board at Western University approved this study (ID# 116473; see Appendix C for approval letter).

3.2.1 Study Design

This study used a between-groups design (*N*= 50) comparing healthcare shiftworkers (SW, *n* = 25) and dayworkers (DW, *n* = 25). Additionally, each healthcare worker participant had an opportunity to invite a proxy-rater (e.g., friend, family member, co-worker) to complete an anonymous survey regarding their driving behaviours (*N* = 50).

As a token of appreciation for their time, healthcare worker participants received a $25 electronic gift card. Proxy-rater participants could enter their email address into a draw for one of four $10 electronic gift cards.

3.2.2 Setting

This study was conducted in Southwestern Ontario, Canada between May 2021 and February 2022. In adherence with COVID-19-related public health mandates, all data was collected remotely via an online survey using a Western University Institutional license of Qualtrics; a telephone call conducted one-to-one with the PhD research candidate; an Actiwatch sleep tracking watch and paper-based documentation either mailed to participants' homes, or closest Purolator pickup points, or through curbside pickup/drop-off at Western University. To promote adherence to study procedures, participants were provided the option to complete the daily driving logs via online survey or paper copy, based on their preferences and whether they had ready access to the online survey immediately following driving.

3.2.3 Participants

3.2.3.1 Target Population and Sample Size Determination

The target population for healthcare workers consisted of nurses, paramedics, allied healthcare professionals (e.g., physical and occupational therapists, dieticians, etc.), medical or laboratory technicians, and related healthcare support staff. These healthcare workers could have front-line care delivery or administrative/managerial roles within a healthcare setting.

To promote equivalent groups at baseline, a minimum of 80% of participants were matched by sex and age (±4 years) between groups. A sample of 50 was determined based on a large effect size (d = 0.8), using t-tests with a two-tailed $\alpha = 0.05$ and $\beta = 0.80$ (Portney & Watkins, 2009).

3.2.3.2 Recruitment

Recruitment strategies for ***healthcare workers*** included: emailing individuals who participated in previous studies and who agreed to be contacted for future research opportunities in the i-Mobile Driving Research Lab; advertising through posters or electronic communications with healthcare employers and/or professional associations; advertising on the i-Mobile Driving Research Lab webpage and social media accounts (e.g., Facebook); and advertising in the monthly Health and Rehabilitation Sciences Newsletter at Western University. Healthcare workers who expressed interest in the study by contacting the research team, were then contacted via telephone to review study procedures and ensure informed consent. Those interested were provided a unique

Qualtrics web link to complete the online consent form. The form provided the opportunity for participants to consent to all study procedures; to the lead researcher purchasing their 3-year uncertified driving record from the Ministry of Transportation (by providing their Ontario Driver License number); and/or to identify a proxy-rater to complete a survey evaluating their driving behaviours. Participants' identity was verified using a unique consent code created during the telephone call.

Healthcare worker participants who consented to having a proxy-rater evaluate their driving via an anonymous survey, were emailed an invitation to send to a ***proxy-rater participant (e.g., friend, family member, colleague)*** of their choice. The email invitation contained a Qualtrics web link and unique participant code to access the letter of information and consent, and the online proxy-rater survey. This study protocol verified that proxy-raters were linked to their respective healthcare worker participant. Since the research team was not directly involved in recruiting proxy-raters, all proxy-rater participants' identities remained anonymous.

3.2.3.3 Study Eligibility

Inclusion criteria for ***healthcare worker participants*** were: (1) employed in the healthcare sector for at least 1 year in either shiftwork (e.g., 12h rotating days/night shifts) or regular dayshifts (e.g., 8:00am to 5:00pm); (2) full-time employment (either through a single full-time job or a combination of multiple part-time or casual roles) working 35-48 hours per workweek on average for the past year; (3) either fully-licensed drivers in Ontario (i.e., G license), or eligible for testing (i.e., G2 road test) for a full license but unable to do so due to the COVID-19 pandemic restrictions (e.g., testing center closures, cancellations, or backlogs); (4) self-reported as fluent in speaking and reading English; and (5) able to complete online questionnaires and follow the outlined study procedures.

Exclusion criteria for ***healthcare worker participants*** were: (1) self-reported medical diagnosis (e.g., neurological, psychiatric, sleep disorder) that interferes with sleep or operating a motor vehicle (e.g., Parkinson's, narcolepsy, driving phobia); (2) self-reported use of prescription medication that interfered with sleep (e.g., insomnia requiring medication) or motor vehicle operation, including medications that affect the central nervous system (e.g., stimulants: Modafinil, amphetamines, or sedatives: Benzodiazepines, anti-epileptic drugs); and (3) scoring

>15/24 on the Epworth Sleepiness Scale (ESS) which is categorized as severe excessive daytime sleepiness and validly indicates an underlying sleep pathology such as narcolepsy or severe sleep apnea (Johns, 1991).

Inclusion criteria for ***proxy-rater participants*** were: (1) they observed the healthcare worker participant drive a motor vehicle at least once in the past three months; (2) were between the ages of 18-85 years; and (3) self-reported as fluent in speaking and reading English. There were no exclusion criteria for proxy-raters.

3.2.4 Data Collection

Figure 3-1 provides a visual overview of data collection procedures for ***healthcare worker participants***. After consent and eligibility procedures, we documented participants' demographic and contact information; driver's license number; preference for either online or paper copy of sleep and driving logs; and preference for mailing and receiving data collection forms (i.e., mail, Purolator, drop-off/pick-up at university). Upon provision of a driver's license number, participant's 3-year uncertified driving record was ordered through Service Ontario.

Healthcare worker participants were then provided a link to an online intake survey comprised of standardized and non-standardized measures examining sleep, sleepiness and chronotype; driving behaviours; driving history; driver and vehicle characteristics; and psychosocial factors, including mental health status and work-life conflict. Next, healthcare worker participants chose their own proxy-raters, (e.g., a friend, family member, co-worker, or caregiver) who has observed them driving at least once in the past three months and provided an email invitation to complete an anonymous survey on Qualtrics evaluating their safe driving behaviours.

After completing the online intake survey and inviting a proxy-rater to evaluate their driving, participants elected a 14-day period to complete twice-daily driving logs (i.e., morning and night) and track their sleep using an Actiwatch Spectrum (Koninklijke Philips N.V.) and sleep log. A study materials package was delivered to participants before their selected 14-day period, containing an overview of study procedures, study team contact information, Philips Actiwatch Spectrum watch and instruction sheet (*See Appendix D*), a paper sleep log (*See Appendix E*), and a sealed envelope containing a stimulus sheet for a cognitive screening test labelled with the time and day of the screening phone call.

The 14-day period began at noon the day before participants' first scheduled work shift of the week and continued for 14 consecutive days, to include two consecutive workweeks and the days off therein. For example, for participants who started work Monday morning, day one would be Sunday at noon. On the final morning of one workweek, participants completed a cognitive screening telephone call lasting approximately 5 minutes. Testing was consistently conducted in the morning for all participants, regardless of group, in order to mitigate the impact of time-of-day and environmental factors that can influence functional performance (Kantermann et al., 2010), such as circadian rhythm and bright light exposure. Shiftworkers completed this phone call at the end of the final night shift, prior to driving home (e.g., 7:15 am for those working until 7:00 am); while day workers completed this prior to driving to work (e.g., 7:15 am for those who leave at 7:30 am to drive to work).

Following the 14-day period, participants returned the study materials (e.g., Philips Actiwatch Spectrum, sleep log). Approximately 4-weeks later, participants were emailed a brief 1-month follow-up survey regarding sleep-related or adverse driving events during this period.

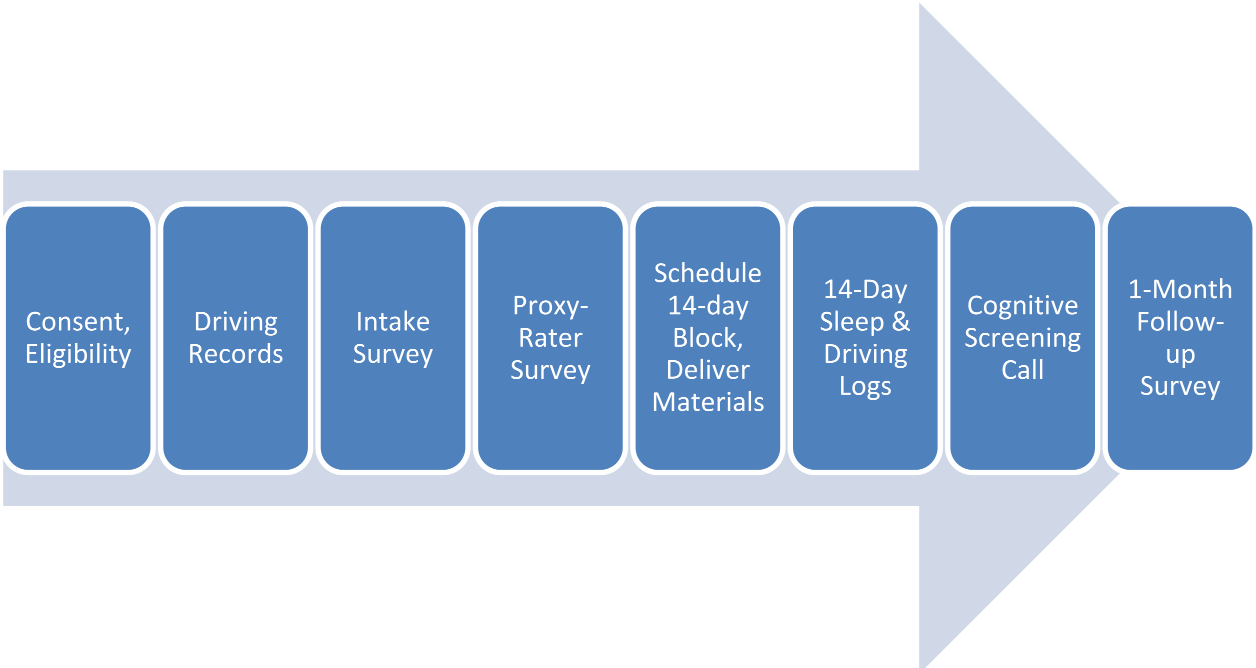


Figure 3-1 Overview of Study Procedures

3.2.4.1 Sleep-Related Measures

Sleep-related measures included sleep quantity (i.e., hours and minutes of sleep), sleep quality (i.e., subjective ratings of sleep quality, and sleep efficiency as a percentage of time asleep), ratings of trait sleepiness (i.e., chronic daytime sleepiness), or state sleepiness (i.e., subjective rating of alertness or sleepiness while driving), along with relevant person characteristics that are known to influence sleep (i.e., chronotype, work-life conflict, mood and anxiety status, and whether participants have dependent children). Outcomes were measured via a combination of self-report using non-standardized forms, standardized questionnaires, and objective measures summarized in Table 3-1 and described below.

Table 3-1 Sleep-Related Outcome Measures

Outcome Measure	Sleep Quantity	Sleep Quality	Sleepiness	Participant Attributes
Past Workweek Sleep Quantity	S			
14-Day Actigraphy, Total Sleep Time	O			
14-Day Actigraphy, Sleep Efficiency		O		
Pittsburg Sleep Quality Index		X		
STOP-Bang		X		
Epworth Sleepiness Scale			X	
Karolinska Sleepiness Scale			X	
Revised Morningness-Eveningness Questionnaire				X
Dependent aged < 18 years				S
Work-Life Conflict				X
Hospital Anxiety and Depression Scale				X

Note: O = Objective measure, S = Self-report non-standardized form, X = Self-report via standardized questionnaire

3.2.4.1.1 Sleep Quantity

3.2.4.1.1.1 Sleep Quantity Past Workweek

Participants were asked to self-report the total number of hours of sleep, including both main sleep and naps in the 24hs before each shift in the past workweek. This question was included in the intake survey.

3.2.4.1.1.2 14-Day Total Sleep Time and Sleep Efficiency

Objective measures for 14-day Total Sleep Time and 14-Day Sleep Efficiency were collected via a Philips Respironics Actiwatch Spectrum (Koninklijke Philips N.V) worn by healthcare worker participants for 14-days on their non-dominant wrist. The Actigraph watch was shipped to each participant in the study materials package. The Actigraph was set to turn on at 12:00pm the day prior to their work week, along with an in instructions page watch setup used to enhance data validity *(See Appendix E)*. Actigraphy is a validated and reliable method used to measure total sleep time, sleep efficiency, and wake after sleep onset compared with in-home polysomnography, but less accurate than sleep lab-based polysomnography (Dunican et al., 2018; Full et al., 2018). While polysomnography conducted in a sleep lab is the established gold-standard for sleep measurement (Ancoli-Israel et al., 2015; Slack et al., 2007), actigraphy is more accessible and it can be used in the participant’s home to capture typical main night sleep and daytime napping (Ancoli-Israel et al., 2015). Outcome measurements included 24h sleep duration and sleep efficiency, with variables tracked to calculate these measures (e.g., bedtime, wake time, time in bed, and total sleep time) outlined in Table 3-2, as defined by Ancoli-Israel and colleagues (2015).

Table 3-2 Actigraphy Measurement Definitions

Variable	**Definition**	**Measurement**
Bedtime	Clock time participant begins to attempt to sleep	Hour/minute
Wake time	Clock time participant awakens in morning	Hour/minute
Time in bed (TIB)	Duration in hours/minutes from bedtime to wake time	Minute epochs
Total sleep time (TST)	Duration in hours/minutes of sleep	Minute epochs
24h sleep duration	Total sleep duration in 24h including main sleep and naps	Minute epochs
Sleep efficiency (SE)	Ratio of time asleep (TST) over time in bed (TIB)	Percentage

Following standard practice in actigraphy, participants completed a hand-written actigraphy log (i.e., sleep log, see *Appendix E*) to aid in Actigraph scoring and interpreting (Ancoli-Israel et al., 2015). Participants were instructed to record information for both main sleep and nap periods, including time they went to bed, attempted to fall asleep, awoke, and got out of bed, along with any sleep disruptions or watch removals (i.e., for bathing). In instances of watch failure, the actigraphy log may be used to: manually calculate 24-hour sleep duration by calculating the time in bed (TIB), and the average Sleep Efficiency (SE) for their participant group (i.e., SW or DW). To determine Total Sleep Time (TST), the TIB was multiplied by the SE (e.g., TIB x SE = TST).

3.2.4.1.2 Sleep Quality

3.2.4.1.2.1 Pittsburg Sleep Quality Index

The Pittsburg Sleep Quality Index (PQSI) (Buysse et al., 1989) examines subjective sleep quality in the past month. Nineteen items measure adult sleep quality and patterns by evaluating seven areas: subjective sleep quality, latency, duration, disturbances, sleep efficiency, as well as the use of sleeping medication and experience of daytime dysfunction. This tool differentiates between good versus poor sleep quality over the past month, with overall scores ranging from 0-21, categorized as Good Sleep Quality (score 0-5) or Poor Sleep Quality (6-21).

3.2.4.1.2.2 STOP-Bang

The STOP-Bang (Chung et al., 2012) is a screening tool to determine risk for obstructive sleep apnea. Eight items are scored as yes/no, with each 'yes' awarded 1 point, with a total score of 0-8. Scores indicate risk for sleep apnea, from Low-Risk (score 0-2), Intermediate Risk (3-4), or High Risk (5-8). Given that untreated sleep apnea is a known independent risk factor for sleep-related MVC (May et al., 2016), it was important to identify those with a higher risk for sleep apnea, a potential confounder in the study.

3.2.4.1.3 Sleepiness

3.2.4.1.3.1 Epworth Sleepiness Scale

The Epworth Sleepiness Scale (ESS;Johns, 1991) quantifies the levels of daytime sleepiness. 8 items are rated for likelihood to fall asleep using a 4-point Likert scale (0 = never to 3 = high chance). Total scores range from 0 to 24. Daytime sleepiness is categorized as: Lower Normal (score 0-5), Upper Normal (6-10), Mild Excessive (11-12), Moderate Excessive (13-15), or Severe Excessive (>15). Those with scores >15 were excluded from this study, as this cutoff validly indicates underlying sleep pathology (i.e., narcolepsy, or severe obstructive sleep apnea) (Johns, 1991). The ESS has established internal consistency reliability (α = 0.88) and test-retest reliability (r = 0.822), and is highly sensitive, identifying 94% of those with sleep disorders, and correctly identifying all who do not have sleep disorders (Shahid et al., 2010; Shahid et al., 2012).

3.2.4.1.3.2 Karolinska Sleepiness Scale

The Karolinska Sleepiness Scale (KSS) is an oral self-report of subjective alertness or sleepiness using a 10-point Likert scale (1= extremely alert to 10 = very sleepy, can't keep awake) (Akerstedt et al., 2017). The KSS has established validity for measuring sleepiness (Kaida et al., 2006), and high scores are predictive of impaired driving performance outcomes in shiftworkers (Knott et al., 2020).

3.2.4.1.4 Person Characteristics

3.2.4.1.4.1 Revised Morningness and Eveningness Questionnaire

The Revised Morningness and Eveningness Questionnaire (rMEQ) examines self-reported chronotype, or preferences for morningness or eveningness (Adan & Almirall, 1991). The rMEQ is a five-item revised short form of the 19-item gold-standard Morningness and Eveningness Questionnaire (MEQ)(Horne & O., 1976). The rMEQ has established criterion validity when compared to the MEQ total score (r_s = 0.898, p = <.0000); and MEQ preference types (r_s = 0.733, p = <.00001)(Adan & Almirall, 1991). The rMEQ categorizes chronotype into one of five preferences: definitely morning type (score 22-25), moderately morning type (18-21), neither type (12-17), moderately evening type (8-11), definitely evening type (4-7). Chronotype has significant implications on sleep quality and quantity, and recovery between day and overnight shifts (Juda et al., 2013; Korsiak et al., 2018; van de Ven et al., 2016).

3.2.4.1.4.2 Hospital Anxiety and Depression Scale

The Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983) uses 14 questions to examine the frequency and intensity of symptoms of anxiety and depression in the past week via a 4-point Likert scale. Scores range from 0-21 on each subscale for depressive and anxiety symptoms, with scores of ≥8 identifying clinically significant symptoms. HADS has established validity and reliability in the general population and in shiftworkers (α = 0.81) (Waage et al., 2014). Partial insufficient sleep has been established to significantly impact measures in the domain of affect (Pilcher & Huffcutt, 1996).

3.2.4.1.4.3 Work-Family Conflict Scale

The Work-Family Conflict Scale (WFC) (Carlson et al., 2000) uses 18 questions divided into three subscales addressing time-based, strain-based, and behaviour-based conflict on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Bi-directional relationships of work interference with family (work-family conflict, WFC) and family interference with work (family-work conflict, FWC) are considered for each subscale. For the purpose of the present study, only time-based and strain-based conflict subscales were administered.

3.2.4.2 Driving Performance Measures

Driving performance measures are outlined in Table 3-3 to demonstrate the multi-modal nature of data collection used to capture and describe healthcare workers' driving history, driving habits, driving behaviours, cognitive skills underlying driving abilities, and driving events. Measures included self-reported outcomes using standardized questionnaires and non-standardized forms, proxy-rater observations of driving behaviours, objective data documented by Ontario Drivers' Records, standardized cognitive screening tools, and driving events captured via 14-day driving logs and 1-month follow up survey. Details of each measure are also outlined in Table 3-3.

Table 3-3 Driving Performance Outcome Measures

Outcome Measure	Driving History	Driving Habits	Driving Behaviour	Driving Abilities	Driving Events
Driving History Form	S				S
Vehicle and Driver Characteristics	S				
3-Year Driving Record		X			
Scale of Fatigued Driving Behaviour		X			
Driving Behaviour Questionnaire			X		
Fitness-to-Drive Screening Measure			P		
Oral Symbol Digits Modalities Test				O	
Oral Trail Making Test A & B				O	
14-Day Daily Driving Logs					S
1-Month Follow-Up Survey					S

Note: O = Objective measure, S = Self-report non-standardized form, X = Self-report via standardized questionnaire, P= Proxy-Report via standardized questionnaire

3.2.4.2.1 Driving History

Driving history is comprised of objective components including the history of driving education, licensing status, drivers' record of citations and infractions (Classen et al., 2017). Included also for this study is the drivers' subjective history of sleep-related and adverse driving events.

3.2.4.2.1.1 Driving History Form

The Driver History Form included questions regarding the drivers' history for driving, driver training, and vehicle technology. Participants were asked to identify whether they had completed formal driver training (basic and/or advanced) and years since training; kilometers driven annually; and whether their primary personal vehicle was equipped with In-Vehicle Information

Systems (IVIS, e.g., blind-spot warning system) or Advanced Driver Assistance System (ADAS, e.g., lane-keeping assist).

Participants also provided a subjective history of sleep-related (e.g., severe sleepiness, nodding off for even a moment, or falling asleep while driving) or adverse driving events (e.g., crossing the center lane, missing turns/lights, memory gaps, crashes). Participants were asked to rate whether they had ever, in the past year or past month, experienced sleep-related or adverse driving events; if so, how often these occurred in the past year or month.

3.2.4.2.1.2 3-Year Driving Record

To compliment the healthcare workers' self-reported driving history, with consent, participant's 3-year uncertified Ontario Driving Records were ordered for review from the Ministry of Transportation of Ontario (MTO). Biases exist in both self-report and driving record data. Drivers may forget some prior near-misses or crashes, and such forgetting increases over time. While a driving record is objective documentation that does not degrade over time, driving record data may not capture near-misses or crashes if these events were neither witnessed by, nor reported to, the police. Thus, by collecting data on driving history from both self-report and driving record reports, researchers may obtain a more comprehensive summary of past driving history than using either method alone. The 3-year driving records included the drivers' name, date of birth, sex, height, license class (e.g., G, M), any conditions and endorsements (e.g., requirement to wear glasses/contact lenses to drive), license status (e.g., licensed, unlicensed, suspended), earliest license date available (e.g., years as a licensed driver), demerit point total, active fine suspensions, and Highway Traffic and Criminal Code of Canada convictions or suspensions.

3.2.4.2.2 Driving Habits

Driving habits are comprised of good or bad driving practices that are repeated over time (Classen et al., 2017), in this study driving habits of interest pertain to driving with sleepiness.

On the intake survey, participants rated how frequently they continued to drive after noticing sleepiness using a 10-point Likert scale (1 = never to 10 = frequently). This question was used to examine participants' habitual response to continuing (or discontinuing) driving after noticing signs of sleepiness. Participants were asked this question once more in the 1-month follow-up survey.

3.2.4.2.2.1 Scale of Fatigued Driving Behaviour

The Scale of Fatigue Driving Behaviour Questionnaire (SFDB) uses 14 items to examine fatigued driving perceptions and behaviours. and is rated using a 5-point Likert scale (1 = strongly disagree/unlikely to 5 = strongly agree/likely). Five subscales included: Subjective Attitude (i.e., SA, 2 items), Subjective Norms (i.e., SN, 3 items), Perceived Behavioural Control (i.e., PBC, 3 items), Fatigued Driving Intention (i.e., SBI, 3 items), Fatigued Driving Behaviour (i.e., SB, 3 items). The TPB-SFDB has high internal consistency reliability ($\alpha = 0.909$) and good validity in predicting self-reported drowsy driving behaviour (Jiang et al., 2017). While the title of this measure includes driving behaviour, the content of this tool is more accurately categorized as driving habits, since the SFDB items and scoring indicate either (dis)agreement or likelihood to engage in driving with sleepiness and does not consider individual driving behaviours required to maneuver a vehicle.

3.2.4.2.3 Driving Behaviour

Driving behaviours required for vehicle control (i.e., strategic, tactical, operational) require varying levels of cognitive control, decision making and interaction with vehicle components (Classen et al., 2017; Michon, 1985; Transportation Research Board, 2016).

3.2.4.2.3.1 Driving Behaviour Questionnaire

The Driving Behaviour Questionnaire (DBQ) (Cordazzo et al., 2016) is a standardized self-report questionnaire comprised of 65-items on the frequency of risky driving behaviours, using a 5-point Likert scale (1= never to 6 = always). Driving behaviour is evaluated across four subscales: Inattention Errors (i.e., IE, 32 items), Age-Related Problems (i.e., ARP, 6 items), Distraction and Hurry (i.e., DH, 20 items), and Aggressive Violations (i.e., AV, 7 items). The DBQ predicts self-reported citations and crashes prospectively and retrospectively (de Winter & Dodou, 2010). Also, the violations subscale was predictive of on-road poorer vehicle control pertaining to speed, lateral position, lane changes, and accelerations; while inattention and lapses subscale was predictive of steering and throttle interactions (Zhao et al., 2012).

3.2.4.2.3.2 Fitness-to-Drive Screening Measure

Healthcare workers' self-reported driving behaviour data (e.g., DBQ) was complimented by adding a proxy-rater measure of safe driving behaviours, via the 21-item Fitness-to-Drive Screening Measure (FTDS)(Classen et al., 2018). Prior to rating the healthcare worker participant's driving, proxy-raters (e.g., friend, family-member, or coworker of the participant) viewed two brief training videos on how to assess performance (1-2 minutes each). Proxy-raters then evaluated the healthcare worker participants on 21 driving behaviours, for example, *"How difficult is it for him or her to drive in an unfamiliar area?"* using a 4-point Likert scale (1 = very difficult to 4 = not difficult). Results provide a score out of 100, and a classification of the driver, if possible, into one of three categories: (1) Accomplished Driver (e.g., able to perform complex driving skills, difficulty only with most complex), (2) Routine Driver (e.g., difficulty with routine driving skills, early signs intervention may be required), or (3) At-Risk Driver (e.g., able to perform basic driving skills, but safety concerns exist that require immediate attention) (Classen et al., 2018). Drivers are then provided with recommendations on three specific driving behaviours that may require improvement. The FTDS validly predicts drivers who will pass versus fail an on-road assessment in older drivers (Area under the curve = 0.726, p = < 0.001; sensitivity = 0.677; specificity = 0.680, PPV = 0.280, NPV = 0.920) (Classen et al., 2015). However, this tool has not been used in research on adults with insufficient sleep; thus while items may be indicative of driving behavior, the hierarchy of the calibrated item difficulty to person ability map may be different from the profiles from the older drivers. However, proxy-rated measures, such as the FTDS, show good concurrent criterion validity with the gold-standard on-road driving test, and may mitigate concerns of recall or rater bias associated with self-reports (Classen et al., 2013).

3.2.4.2.4 Driving Abilities

Driving abilities are comprised of the neurocognitive, neurobehavioural, or sensory-perceptual skills required to control a vehicle throughout typical driving environments or conditions (Classen et al., 2017; Transportation Research Board, 2016). Given the remote nature of this study during the COVID-19 pandemic, a comprehensive clinical assessment of driving abilities was not possible; thus, this study focused on the cognitive skills screening via telephone.

Driving abilities were evaluated via screening cognitive skills required for driving (e.g., visual scanning and information processing speed; alternating, divided and selective attention). This was achieved via a brief telephone screening, using tools validated for oral administration to be equivalent to in-person written administration, specifically the Oral Trail Making Test A and B (OTMT-A, OTMT-B) and Oral Symbol Digits Modalities Test (O-SDMT) (Jaywant et al., 2018).

3.2.4.2.4.1 Oral Trail Making Test A and B

The OTMT-A involves asking the participant to count from 1 to 25 as quickly and accurately as possible, with the time and number of errors recorded. The OTMT-B requires the participant to alternate between numbers and letters (e.g., 1-A-2-B-3-C) stopping at 13. The total time in seconds, and total errors are recorded. Participants' performance was compared to normative data for the OTMT-A and OTMT-B (Mrazik et al., 2010), with time to complete (seconds, *z*-score) and number of errors (number, *z*-score). Finally, we established whether performance was deemed as impaired based on the 9th percentile for OTMT scores in seconds, in accordance to age and gender stratification. The OTMT-A shows adequate concurrent and predictive validity, while the OTMT-B shows excellent construct and concurrent validity (Jaywant et al., 2018).

3.2.4.2.4.2 Oral Symbol Digits Modalities Test

Participants were provided the O-DSMT stimulus sheet in the study materials package, in a sealed envelope to prevent advanced review of the test. Participants were then instructed to open this envelope during the phone call and review the symbol-number key (e.g., numbers 1-9 aligned with a series of symbols). Below this, a series of symbols appeared with blanks for the corresponding numbers, and participants were instructed to read out the corresponding numbers in order, practicing with the first 10 symbols (feedback was given on any errors to ensure proper use of the symbol-number key). Next, participants were instructed to read out the correct numbers for the symbols displayed as quickly and accurately as possible in 90 seconds, with the score being the total number of correct responses given. Participants' performance was compared to normative data stratified by age, gender, and formal education above or below 16 years (Strober et al., 2020). The SDMT is commonly used in clinical settings to identify those at risk of cognitive impairment with high sensitivity and specificity (Strober et al., 2020), with the O-

SDMT demonstrating excellent construct and predictive validity and test-retest reliability (Jaywant et al., 2018).

3.2.4.2.5 Driving Events

3.2.4.2.5.1 14-Day Driving Logs

Driving events were tracked prospectively during a 14-day period, concurrently with participants' sleep quantity and quality. Throughout the 14-day data collection period, healthcare worker participants completed twice-daily driving logs, either via an online survey link emailed each morning and night, or via a paper log mailed to them in the study materials package. Participants were asked to complete this driving log as soon as possible following their driving (i.e., within 30 minutes if possible). The daily driving log form (*Appendix F)* is based on a published driving log used in three prior research studies (Anderson et al., 2018; Ftouni et al., 2013; Mulhull et al., 2019) and was modified to suit the needs of this study.

The daily logs captured details about whether participants worked, drove, or used any substances in the past 12h, and had embedded skip logic, such that if participants responded that they did not work, drive, or use substances in this 12h period, the relevant questions were skipped. If participants did work and drive, all questions were displayed, including work and sleep hours.

Driving data included time of day, length of drive, driving environment (i.e., traffic and weather conditions), and destination and purpose of drive (e.g., commute to work, leisure trip, etc.). Participants were asked to rate their sleepiness using the KSS (Akerstedt et al., 2017) at the start, end, and maximum during the drive (1 = very alert to 10 = very sleepy, can't keep awake). Participants noted whether any adverse driving events occurred, with events summed overall, and categorized into four subscales: Sleep-Related (e.g., resting eyes, fall asleep, fall asleep at stop light, nod off, startle awake); Inattention (e.g., fixation in interior/exterior object, lack of awareness, being distracted, memory gaps); Hazardous (e.g., braking sharply, hitting rumble strips, swerving violently, missing a turn, wandering lanes, crossing the centre line, arriving at an unintended destination, someone honking at them, or a near miss); and Violations (e.g., driving through a stop light, yelling at another driver, crash). Finally, participants were asked whether they engaged in any countermeasures (e.g., eating, cold air, making a call), and whether they consumed any substances in the past 12h, including caffeine, alcohol, cannabis, and prescription- or over-the-counter medications.

3.2.4.2.5.2 One-Month Follow Up Survey

One month after the conclusion of the above 14-day prospective data collection period, healthcare worker participants also completed a brief follow up survey. Questions included whether they had experienced any sleep-related driving events (e.g., severe sleepiness, nodding off, falling asleep), and/or adverse driving events (e.g., near-misses, wandering lanes, missing turns/intersections), and the number of such occurrences. For clarity, participants were asked whether any changes in vehicles/driver assistance technology occurred in the past month, as vehicle technology changes may influence instances of adverse driving events through advanced driver assistance systems.

3.2.4.3 Data Management

Healthcare worker participants were provided with a unique ID Code (e.g., 11-XX) to use on all forms to de-identify their data, with their identifying information and participant ID Code stored in a separate, password-protected and encrypted file for security. Proxy-raters were also provided a unique ID code to enter, to link to the healthcare worker (e.g., P-11-XX) to ensure accurate data tracking.

The PhD Candidate prepared and maintained a master participant database tracking participant progress and contact information, with the master participant list restricted only to the PhD Candidate and Principal Investigator (Dr. Alvarez) on a secure research drive. The PhD Candidate coordinated data collection and monitored participant responses to online questionnaires and provided reminders for outstanding items to promote adherence with data collection protocols.

The online surveys were administered using a Western University institutional Qualtrics license, and subsequently exported and securely stored on a secure Western University server with restricted access to study team members per the approved ethics protocol. Hand-written data (e.g., cognitive screening tools OTMT-A, OTMT-B, and O-SDMT; daily driving logs if hard copies were requested), were entered into a Microsoft Excel spreadsheet by a trained research student or the PhD Candidate and all were verified by the PhD Candidate for data accuracy. Verified data was then exported to SPSS for analysis.

The PhD Candidate prepared all Actigraph Spectrum watches for data collection, ensured sleep/wake data was de-identified and labelled by participant ID, uploaded participant data from Actiwatches to Actiware software (Koninklijke Philips N. V.) for scoring in the BMI Sleep Lab Control Room computer. Initial scoring and interpretation was completed by two trained research students, in pairs, to ensure data accuracy. Once preliminary scoring was completed, the PhD Candidate verified all data scoring and interpretation, exported summary statistics reports and raw data via Microsoft Excel spreadsheet from Actiware Software. Data was transformed using Microsoft Excel to ensure appropriate data form for analysis in SPSS.

3.2.4.4 Data Analysis

The statistical analysis and data displays were completed using SPSS v.27.0 (IBM, 2022) and/or Microsoft Excel. Descriptive statistics were used to characterize outcomes of each group (e.g., mean, median, standard deviations, range, *z*-score, percent, frequency of outcomes above or below a defined cutoff). Inferential statistics were calculated to determine between-groups differences for participant characteristics, sleep-related outcomes, and driving performance outcomes outlined above. Continuous data were analyzed via parametric tests (e.g., independent samples *t*-tests) or non-parametric tests (e.g., Mann-Whitney U test) if the assumptions of normality were not met. Nominal data were analyzed using non-parametric tests (e.g., Chi-Square Test, or Fisher's Exact Test). To protect against Type I errors arising from multiple comparisons, Bonferroni adjusted alpha levels were used to identify statistically significant results where more than two analyses were completed on the same dependent variable (Portney & Watkins, 2009). The adjusted alpha level was computed by α/c, where c = number of tests (Portney & Watkins, 2009).

3.3 Results

3.3.1 Participant Flow

As shown in Figure 3-2, 51 healthcare workers (25 SW and 26 DW) provided consent for eligibility screening. One participant did not respond further and was replaced, and three were ineligible based on inclusion criteria (e.g., work status) or exclusion criteria (e.g., medical diagnosis) for a total of 47 participants. All 23 eligible SW completed the study procedures. Missing data comprised one participant declining consent specifically for driving records, one participant not responding to the request for driving records, and one Actigraph watch data loss. Of the 24 eligible DW two participants withdrew mid-study due to self-reported changes in eligibility (e.g., work or health status). The remaining 22 DW completed all study procedures with missing data items including one driving record, one proxy-rater survey, and one set of sleep data (neither Actigraph nor sleep log data provided). Therefore, the final sample included 23 SW with 21 full datasets and 22 DW with 20 full datasets.

Of the 47 eligible healthcare worker participants, 46 (97.8%) consented to inviting a proxy-rater of their choosing to complete the FTDS measure, comprised of 23 SW and 23 DW invitations. Of these, 42 responses were returned. Missing responses were comprised of one healthcare participant withdrawal, and three proxy-rater participants not responding to the invitations.

Almost all participants (97.8%) provided 14-day sleep data via Actigraph and/or sleep logs; one participant's sleep log and actigraphy data was not provided. Otherwise, 93.3% of participants provided Actigraph data, with one participant from each group providing sleep log data only, due to either Actiwatch technology failure or participant intolerance to watch materials. The analysis of objective sleep data captured over this period is comprised of 619 days of Actigraph data from 23 SW and 21 DW participants.

Overall, 94.5% of the twice-daily driving logs were returned from 45 participants, representing 1191 drives. The SW group returned 96.3% (n = 620) of driving logs, while the DW group returned 92.7% (n = 571) of driving logs, (χ^2 = 7.789, $df = 1$, p = .005).

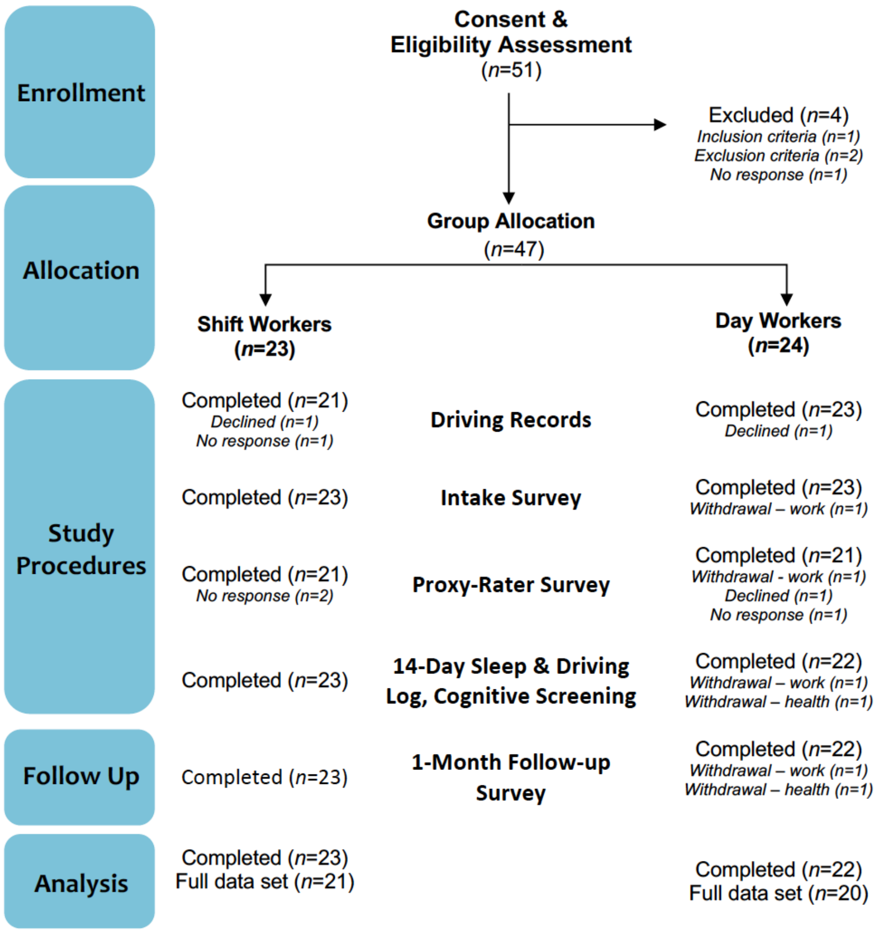


Figure 3-2 Study Participant Flow Diagram

3.3.2 Participant Characteristics

3.3.2.1 Healthcare Workers

As shown in Table 3-4, there were no significant differences between SW and DW groups in age (p = .347), sex (p = 0.833), level of education (p = .117), years of work experience (p = .292), primary employment status (p = .463), nor whether participants were responsible for a dependent under the age of 18 years (p = .273).

As expected, SW's average shift duration in the past month was greater at 11.8h (versus 8.3h for DW) and with a greater maximum duration of 13.5h (versus 9.6h for DW), (p <.001). Concurrent to the shorter shift duration, the DW group reported working a greater number of shifts in the past month, at 18.4 shifts (versus 14.6 shifts for SW) (p = .003).

There was a significant difference in occupations between SW and DW groups ($\chi^2 = 18.44$, $df = 3$, $p = <.001$). The SWs were comprised of nurses (e.g., registered or practical nurses) (69.6%) and paramedics (30.4%), while DW were comprised of nurses (34.8%), paramedics (19.6%), allied health professionals (e.g., occupational or physical therapists, dieticians, kinesiologists) (13.0%), and other health care staff (e.g., technicians, support workers, researchers, managers).

3.3.2.2 Proxy-Raters

Of the 42 proxy-raters, the majority were female (61%), with an average age of 34.5 ± 11.8 years (R = 18 - 63), held valid driver's licenses (92.7%), and drove 6 or 7 days per week (70.7%). Participants self-identified as Caucasian (88.1%), Black (4.8%), or Arab, Chinese, Korean or South Asian (2.4% each). The majority of proxy-raters reported post-secondary education (39.1%), an advanced or professional degree (24.4%), or some vocational or college-level training (21.9%).

Table 3-4 Healthcare Worker Participant Characteristics (*N*= 47)

Characteristics	Shiftworkers (SW) (*n* = 23)	Day Workers (DW) (*n* = 24)	Significance ($p \leq .05$)
Age (years)	32.0 ± 12.2 (21-58)	31.5 ± 10.1 (20-56)	.347
Sex			.833
Female	65%	79%	
Male	35%	21%	
Parent to child <18 years	48%	29%	.273
Ethnicity			
Caucasian	95.7%	83.3%	
Other	4.3%	12.6%	
Did not disclose	—	4.2%	
Level of Education			.117
College diploma	30.4%	20.8%	
Undergraduate degree	69.6%	50.0%	
Graduate Degree	—	20.8%	
Did not disclose	—	4.2%	
Occupation			**<.001**
Nurse	69.6%	33.3%	
Paramedic	30.4%	8.3%	
Allied Health	—	29.2%	
Other	—	29.2%	
Primary Employment			.223
Full time, 1 job	87.0%	87.0%	
Full time, >1 job	4.3%	13.0%	
Part time, plus call-in[1]	8.6%	—	
Work experience (years)	10.8 ± 9.2 (1-34)	9.2 ± 7.8 (1-24)	.292
Past Month,			
Number of shifts	14.6 ± 3.8 (4-22)	18.4 ± 5.0 (0-28)	**.003**
Shifts with overtime	2.5 ± 2.1 (0-8)	1.5 ± 2.4 (0-10)	.079
Longest shift length (h)	13.5 ± 1.9 (8.0-16.0)	9.5 ± 1.7 (7.5-13.5)	**<.001**
Usual shift length (h)	11.8 ± 0.8 (8.0-12.0)	8.4 ± 1.3 (7.5-13.0)	**<.001**

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. [1]Full-time equivalent work hours (FTE) arising from total of part-time and call-in shifts. Significance level is set at $p \leq .05$.

3.3.3 Sleep-Related Outcomes

3.3.3.1 Self-Reported Sleep Quantity

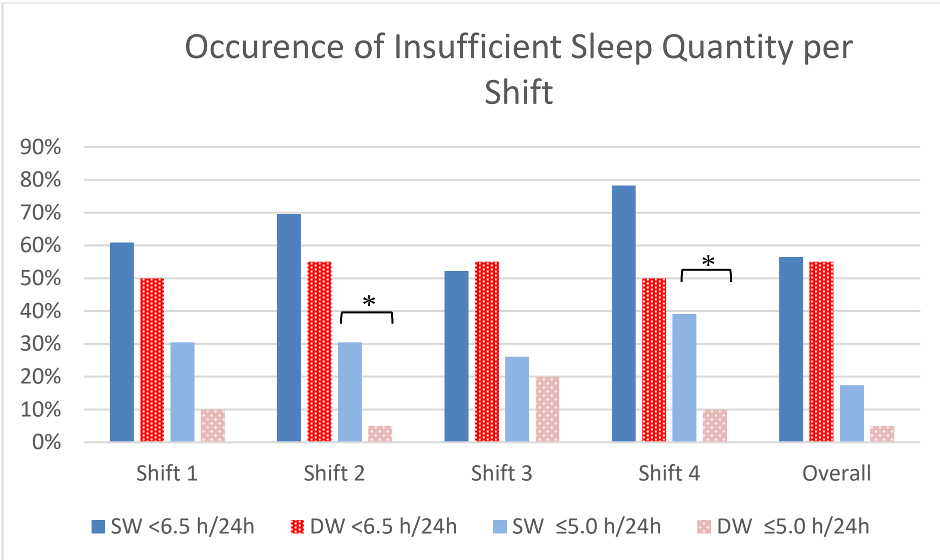
Participants' self-reported sleep quantity during their most recent workweek is detailed in Table 3-5. The SW reported significantly fewer hours of sleep than DW in shift 2 (SW, *M* = 5.65h/24h versus DW, *M* = 6.80/24h, M difference = 1.15h/24h, *p* = 0.006), shift 4 (SW, *M* = 5.78h/24h versus DW, *M* = 6.68h/24h, M difference = 1.02, *p* = 0.10), and overall (SW, *M* = 6.08h/24h versus DW, *M* = 6.7h/24h, M difference = 0.63h, *p* = 0.21).

Table 3-5 Self-Reported Sleep Quantity, Past Workweek

Sleep Quantity per shift (h/24h)	**Shiftworkers (SW)** (*n* = 23)	**Day Workers (DW)** (*n* = 23)	**Significance** (*p* ≤ .05)
	M ± SD (Range)	*M ± SD (Range)*	
Shift 1	6.03 ± 1.86 (2.0-10.0)	6.76 ± 1.17 (4.5-9.0)	.132
Shift 2	5.65 ± 1.44 (2.0-8.0)	6.80 ± 1.15 (5.0-9.0)	**.006**
Shift 3	6.70 ± 2.58 (0.0-12.0)	6.47 ± 1.14 (5.0-8.5)	.714
Shift 4	5.78 ± 1.04 (4.0-8.0)	6.80 ± 1.17 (5.0-9.0)	**.010**
Overall	6.05 ± 0.91 (4.3-7.6)	6.68 ± 1.04 (5.0-8.5)	**.021**

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. Significance level is set at *p* ≤.05.

Figure 3-3 depicts the occurrence of mild insufficient sleep (<6.5h/24h, shaded dark blue and red) or severe insufficient sleep (≤5.0h/24h, shaded light blue and light red) in the past workweek. The occurrence of mild insufficient sleep (<6.5h/24h) in the past workweek did not significantly differ between SW and DW groups (SW, 52-78% versus DW, 50-55%). However, the occurrence of severe insufficient sleep (≤5.0h/24h) was significantly higher in SW, ranging from 26% to 39% per shift (versus 5% to 20% in DW). Significant differences in the occurrences of severely insufficient sleep were noted on Shift 2, with 30% of SW (versus 5% of DW), (χ^2 = 4.570, *df* = 1, *p* = .033); and on Shift 4, with 39% of SW (versus 10% of DW) (χ^2 = 4.768, *df* = 1, *p* = .029).



* *Note:* Significant at $p \leq .05$ level

Figure 3-3 Occurrences of Insufficient Sleep Quantity per Shift

3.3.3.2 Objective Sleep Quantity

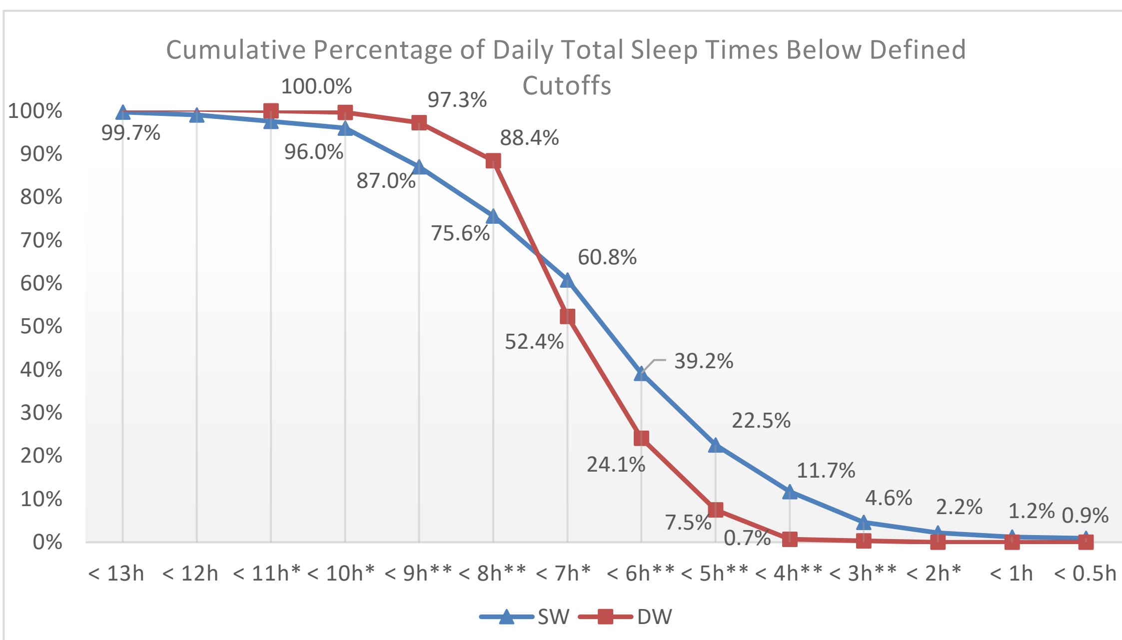
Actiwatch data over the 14-day period captured objective sleep quantity via the Total Sleep Time (TST), shown in Table 3-6. SW compared to DW obtained significantly lower TST overall during the 14-day period (SW, M = 6.55h/24h versus DW, M = 6.77/24h, M difference = 0.22/24h, $p = .036$), and on day shifts (SW, M = 5.78/24h versus DW, M = 6.58/24h, M difference = 0.8/24h, $p < .001$), with no difference on days off. While no statistical comparisons are made on night shift data, it is notable that SW obtained M = 6.03/24h sleep on night shifts, a difference of M = 0.53h/24h less than the lowest TST in the DW group (day shift M = 6.58/24h).

Table 3-6 Total Sleep Time (TST) over 14 Days

Sleep Measures	**Shiftworkers (SW)** (*n* = 22)		**Day Workers (DW)** (*n* = 20)		**Significance** ($p \leq .05$)
	M ± SD	*Range*	*M ± SD*	*Range*	
14-Day Total Sleep Time (TST, h/24h)					
Overall	6.55 ± 2.15	0-14.2	6.77 ± 1.22	2.0-11.8	**.036**
Day Shifts	5.78 ± 1.2	1.8-8.68	6.58 ± 1.1	2.0-9.15	**<.001**
Night Shifts	6.03 ± 2.6	0-12.4	—	—	—
Days Off	7.40 ± 2.0	1.8-14.2	7.13 ± 1.4	3.12-11.1	.133

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. Significance level is set at $p \leq .05$.

Notably, when examining the TST there is a large overall range in the data. SW's TST ranged from 0.0-14.4h/24h, while DW TST ranged from 2.0-11.8h/24h, with large standard deviations therein. While no significant differences exist at the extremes (e.g., <12-13h or <1h), significant differences do exist between the percentages of sleep logs documenting total sleep time within the ranges of 2h to 11h/24h, as shown in Figure 3-4. The SW group data shows a higher overall percentage of days with levels at or below cutoffs for mild and severe insufficient sleep. 39.2% of sleep logs in SW group show TST <6h/24h (versus 24.1% of DW, *p* <.001), indicating insufficient sleep at levels known to result in functional performance deficits. Further, 22.5% of SW daily sleep logs show severe insufficient sleep with TST <5h/24h (versus 7.5% of DW) (χ^2 = 28.362, *df* = 1, *p* <.001), with 11.7% SW logs documenting <4h/24h sleep (vs 0.7% of DW, *p* <.001).



Note: Signficant differences indicated by * = *p* ≤.05, ** = ≤.001, SW (*n* = 22), DW (*n* = 20)

Figure 3-4 Cumulative Percentage of Daily Total Sleep Times Below Cutoff

3.3.3.3 Self-Reported Sleep Quality, Sleepiness, and Person Characteristics

Table 3-7 shows sleep quality, sleepiness and chronotype in SW vs DW. The SW showed poorer sleep quality than DW, as determined by higher PSQI global scores ($t(43) = 3.02$, $p = .004$) and greater percentage categorized as poor sleep quality (95.7% versus 69.6% DW, $\chi^2 = 4.499$, $df = 1$, $p = .034$). Further, significant differences in sleep apnea risk were noted via the STOP-Bang questionnaire, with SWs reporting a greater number of risk factors than DW ($t(44) = 2.168$, $p = .036$). These overall differences resulted in clinically significant differences in overall sleep apnea risk categorization: while 69.6% of SW were deemed low risk (versus 95.7% DW), 26.1% of SW deemed medium risk (versus 13% DW) ($\chi^2 = 6.947$, $df = 2$, $p = .031$). Despite differences in sleep quality and sleep apnea risk, there were no significant differences in daytime sleepiness levels on the ESS score nor categorization of degree of daytime sleepiness.

Person characteristics influencing sleep and sleepiness included chronotype, work-life conflict and symptoms of anxiety and depression. Significant differences existed in the overall chronotype score on rMEQ ($t(43) = 12.919$, $p = .006$), suggesting a trend towards later timing preferences in the DW group. However, these score differences did not result in statistically significant difference in chronotype classifications ($p = .199$). Scores on work to family conflict (WFC) were significantly higher for SW on both time-based ($p < .001$) and strain-based ($p = .023$) factors. There were no differences in symptoms of anxiety and depression.

Table 3-7 Self-Reported Sleep Quality, Daytime Sleepiness, and Person Characteristics

Sleep Measures	**Shiftworkers (SW)** (*n* = 23)	**Day Workers (DW)** (*n* = 23)	**Significance** ($p \leq .05$)
Sleep Quality (Pittsburg Sleep Quality Index, PSQI)			
PSQI Global Score (0-21)	10.9 ± 2.9 (3-19)	8.0 ± 3.6 (3-17)	**.004**
PSQI Category,			**.034**
Good Sleep Quality (0-5)	4.3%	26.1%	
Poor Sleep Quality (6-21)	95.7%	69.6%	
Sleep Apnea Risk (STOP-Bang Questionnaire)			
STOP-Bang Score (0-8)	2.13 ± 1.6 (0-7)	1.30 ± 0.97 (0-5)	**.018**
STOP-Bang Category,			**.031**
Low-Risk (0-2)	69.6%	95.7%	
Moderate Risk (3-4)	26.1%	—	
High Risk (5-8)	4.3%	4.3%	
Daytime Sleepiness (Epworth Sleepiness Scale, ESS)			
ESS Score (0-24)	6.83 ± 3.47 (1-13)	5.42 ± 2.86 (1-12)	.135
ESS Category,			.541
Lower Normal (0-5)	34.8%	50.0%	
Upper Normal (6-10)	52.2%	45.8%	
Mild Excessive (11-12)	8.7%	4.2%	
Moderate Excessive (13-15)	4.3%	—	
Chronotype (Revised Morningness and Eveningness Scale, rMEQ)			
rMEQ Score (0-25)	14.43 ± 3.6 (6-21)	17.50 ± 3.5 (11-24)	**.006**
rMEQ Category,			.199
Definitely Morning (22-25)	—	13.0%	
Moderately Morning (18-21)	21.7%	34.8%	
Neither Type (12-17)	62.5%	43.5%	
Moderately Evening (8-11)	8.7%	4.%	
Definitely Evening (4-7)	4.3%	—	
Work-Family Conflict (WFC) and Family-Work Conflict (FWC)			
WFC Score			
Time-based conflict (0-15)	11.4 ± 2.4 (5-15)	8.2 ± 2.7 (4-15)	**<.001**
Strain-based conflict (0-15)	10.9 ± 2.4 (6-14)	9.1 ± 2.7 (6-15)	**.023**
FWC Score			
Time-based conflict (0-15)	6.1 ± 2.7 (3-9)	5.6 ± 2.0 (3-12)	.415
Strain-based conflict (0-15)	6.4 ± 2.5 (2-12)	5.8 ± 2.6 (3-12)	.392
Hospital Anxiety and Depression Scale (HADS)			
HADS Score			
Anxiety (0-21)	8.9 ± 3.3 (4-15)	9.3 ± 3.3 (4-15)	.650
Depression (0-21)	6.2 ± 3.8 (1-15)	6.8 ± 3.3 (1-14)	.604

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. Significance level is set at $p \leq .05$.

3.3.3.4 Objective Sleep Quality

Sleep Efficiency (SE) was objectively measured via actigraphy during the 14-day period, with data detailed in Table 3-8. SW actigraphy data showed significantly lower for SE (versus DW) overall during the 14-day period (p = .001) was and on days off (p = .017), however, no differences existed on day shifts.

Table 3-8 Sleep Efficiency (SE) Over 14-day Period

Sleep Measures	**Shiftworkers (SW)** (n = 22)		**Day Workers (DW)** (n = 20)		**Significance** ($p \leq .017$*)
	M ± SD	*Range*	*M ± SD*	*Range*	
14-Day Sleep Efficiency (SE, %)					
Overall	80.3 ± 12.3	15.3-99.8	82.2 ± 8.3	41.2-95.2	**.001**
Day Shifts	81.7 ± 9.8	42.5-99.8	81.9 ± 8.4	41.2-95.2	.754
Night Shifts	77.6 ± 15.8	15.3-96.5	—	—	—
Days Off	81.1 ± 11.2	36.4-99.8	83.3 ± 7.7	43.7-93.0	**.017**

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. *Statistical significance using Bonferroni corrected alpha = .05 /3 = .017.

3.3.4 Driving Performance Outcomes

3.3.4.1 Driving History

3.3.4.1.1 3-Year Driving Records

Three-year uncertified driving records from the Ontario Ministry of Transportation were obtained for 21 SW (91%) and 23 DW (96%). Overall, one SW and three DW had positive driving records (i.e., indicating 1 or more citation on the record). One SW (4.8%) had one citation for disobeying a stop sign; and, three DW (13%) had speeding citations (R = 1-3 citations). Fishers' Exact test showed no significant differences between drivers with and without a positive driving record in SW and DW (p = .609).

3.3.4.1.2 Driving History Form

Driver and vehicle characteristics showed that 91% of participants completed basic driver education. Additionally, 19.5% reported completing advanced driver education. There were no significant differences between groups for the completion rate of basic (p = .233) or advanced driver training (p = .457); nor years since training (SW, M = 15.5 ± 10.6 years, versus DW, M = 15.9 ± 9.7 years, p = .905). Overall, 28% of participants reported using in-vehicle information systems (IVIS), and 19.5% reported using advanced driver automation systems (ADAS). There were no significant differences between groups for IVIS (p = .372) or ADAS technology use (p = .297).

As shown in Table 3-9, significant differences existed between SW and DW groups for the occurrences in the past year for severe sleepiness (SW, 91.3% vs DW, 34.8%, χ^2= 15.769, df = 1, p < .001), nodding off (SW, 60.9% vs DW, 17.4%, p = .003), or falling asleep (SW, 26.1% vs DW, 4.3%, p = .040).

The percentage of adverse driving events were examined for any adverse event, sleep-related, inattention, hazardous, or violation events. Findings show that SW were significantly more likely than DW to report any adverse event in the past year (SW, 95.5% vs DW, 45.5%, p <.001), as well as sleep-related events or hazardous events (SW, 69.6% vs DW, 36.4%, p = .026), and inattention events (SW, 65.2% vs DW, 22.7%, p = .004).

SW reported a significantly greater number of types of any adverse events in the past year (*Mdn* = 4 in SW versus *Mdn* = 0 in DW, U = 84.5, z = 3.760, p <.001). Significant differences were shown for the types of adverse events reported in categories of sleep-related, inattention, and hazardous events; with no difference in types of events for violation events. Finally, SW reported a greater total median number of occurrences of adverse events in the past year (*Mdn* = 9 in SW versus *Mdn* = 1 in DW, U = 125, z = -2.936, p = .003). Again, significant differences remained for the number of occurrences of adverse events for each category of sleep-related, inattention, and hazardous events, but not for violation events (p = .975).

Table 3-9 Self-Reported History of Sleep-Related and Adverse Driving Events

Driving Event Type	Shiftworkers (SW) (*n* = 23)	Day Workers (DW) (*n* = 23)	Significance ($p \leq .05$)
Sleep-Related Driving Events	*Percent, or Median (Range)*	*Percent, or Median (Range)*	
Severe sleepiness			
Past 12 months	91.3%	34.8%	**<.001**
Past 1 month	69.6%	21.7%	**<.001**
Number, past month[a]	2.0 (0-20)	0.0 (0-2)	**<.001**
Nodding off			
Ever	73.9%	47.8%	.070
Past 12 months	60.9%	17.4%	**.003**
Past 1 month	31.8%	17.4%	.260
Number, past month[a]	0.0 (0-4)	0.0 (0-2)	.165
Falling asleep			
Ever	52.2%	26.1%	.070
Past 12 months	26.1%	4.3%	**.040**
Past 1 month	8.7%	4.3%	.550
Number, past month[a]	0.0 (0-1)	0.0 (0-1)	.581
Adverse Driving Events, past year			
Any Adverse Event			
Percent reporting	95.5%	45.5%	**<.001**
Types of events[a]	4.0 (0-9)	0.0 (0-5)	**<.001**
Number of occurrences[a]	9.0 (0-245)	1.0 (0-70)	**.003**
Sleep-Related Event			
Percent reporting	69.6%	36.4%	**.026**
Types of events[a]	2.0 (0-3)	0.0 (0-2)	**.003**
Number of occurrences[a]	3.0 (0-63)	0.0 (0-40)	**.020**
Inattention Event			
Percent reporting	65.2%	22.7%	**.004**
Types of events[a]	1.0 (0-1)	0.0 (0-1)	**.005**
Number of occurrences[a]	1.0 (0-40)	0.0 (0-10)	**.033**
Hazardous Event			
Percent reporting	69.6%	36.4%	**.026**
Types of events[a]	1.0 (0-5)	0.0 (0-3)	**.006**
Number of occurrences[a]	3.0 (0-166)	0.0 (0-30)	**.021**
Violation Event			
Percent reporting	4.3%	4.5%	.974
Types of events[a]	0.0 (0-1)	0.0 (0-1)	.975
Number of occurrences[a]	0.0 (0-1)	0.0 (0-1)	.975

<u>Note:</u> Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. [a] = Independent Samples Mann-Whitney U Test. Significance level is set at $p \leq .05$.

3.3.4.2 Driving Habits

Table 3-10 summarizes participants' driving habits after noticing sleepiness and on the Scale of Fatigued Driving Behaviour (SFDB).

Findings show that at the intake survey (i.e., start of the study), SW were significantly more likely to continue driving after noticing sleepiness (SW, *Mdn* = 8 vs DW, *Mdn* = 3, $U = 136.0$, $z = -2.717$, $p = .007$) than DW. However, at the 1-Month follow up survey (i.e., conclusion of the study), no significant differences were found between groups (SW *Mdn* = 6 vs DW *Mdn* = 3, $U = 176.5$, $z = -1.764$, $p = .078$). No differences were found between groups on the SFDB subscales of Subjective Attitudes, Subjective Norms, and Perceived Behavioural Control.

Table 3-10 Mean Responses on Measures of Driving Habits

Measure	**Shiftworkers (SW)** (*n* = 23)	**Day Workers (DW)** (*n* = 23)	**Significance** ($p \leq .05$)
Driving After Noticing Sleepiness	*Median (Range)*	*Median (Range)*	
Continue driving after sleepiness (1 = never, 10 = frequently)			
Intake Survey [a]	8.0 (1-10)	3.0 (1-10)	**.007**
1-Month Follow up Survey [a]	6.0 (1-10)	3.0 (1-10)	.078
Scale of Fatigued Driving Behaviour (SFDB)			
SFDB Score	*Mean ± SD*	*Mean ± SD*	
Subjective Attitudes	2.13 ± 0.68	2.34 ± 0.61	.260
Subjective Norms	2.89 ± 1.3	2.76 ± 1.12	.716
Perceived Behavioural Control	2.26 ± 1.05	2.30 ± 0.89	.880

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. [a] = Independent Samples Mann-Whitney U Test. Significance level is set at $p \leq .05$.

3.3.4.3 Self-Reported and Proxy-Rated Driving Behaviours

Table 3-11 presents self-reported driving behaviour on the DBQ and proxy-rated driving behaviour on the FTDS of healthcare worker participants. No significant findings were found on the DBQ scores, FTDS scores, or driver classification between groups.

Table 3-11 Self-Reported and Proxy-Rated Driving Behaviour (*N* = 41)

Measure	Shiftworkers (SW) (*n* = 21)	Day Workers (DW) (*n* = 20)	Significance ($p \leq .05$)
Self-Reported Driving Behaviours			
Driving Behaviour Questionnaire (DBQ)			
DBQ Full Scale	1.98 ± .49	1.87 ± .34	.385
Inattention Errors	1.67 ± .41	1.57 ± .34	.386
Age-Related Problems	1.92 ± .84	1.88 ± .71	.876
Distraction and Hurry	2.64 ± .73	2.52 ± .51	.545
Aggressive Violations	1.60 ± .48	1.37 ± .32	.061
Proxy-Rated Driving Behaviour			
Fitness-to-Drive Screening Measure (FTDS)			
FTDS Score	70.21 ± 15.82	75.42 ± 14.32	.277
FTDS Classification,			.199
Cannot Classify	9.5%	15.0%	
At-Risk Driver	4.8%	-	
Routine Driver	57.0%	30.0%	
Accomplished Driver	28.6%	55.0%	

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. Significance level is set at $p \leq .05$.

3.3.4.4 Cognitive Skills Underlying Driving Abilities

Table 3-12 shows the cognitive skills underlying driving abilities. Assessments occurred between 5:10 am to 9:15 am, and there were no significant between-groups differences in the time of day of the assessments ($p = 0.266$). No significant differences were found between SW and DW on any of the cognitive screening tests (OTMT-A, OTMT-B, O-SDMT).

Table 3-12 Cognitive Screening Test Results (*N* = 45)

Measure	Shiftworkers (SW) (*n* = 23)	Day Workers (DW) (*n* = 22)	Significance ($p \leq .017$*)
Assessment time	7:06 am ± 34 min	6:50 am ± 54 min	.226
OTMT-A			
Time (sec)	7.61 ± 1.63	7.05 ± 1.26	.207
z-score	-0.86 ± 1.28	-0.42 ± 0.89	.196
Errors	0	0	-
Performance impaired (below 9th percentile)	30.4%	18.2%	.339
OTMT-B			
Time (sec)	34.05 ± 24.31	32.35 ± 14.13	.775
z-score	0.33 ± 1.68	0.23 ± 0.95	.812
Errors	0.91 ± 1.31	0.59 ± 0.80	.327
Performance impaired (below 9th percentile)	21.7%	22.7%	.936
O-SDMT			
Total correct responses (*n*)	61.17 ± 8.37	59.50 ± 8.99	.521
z-score	-0.33 ± 1.08	-0.89 ± 1.36	.132
Performance impaired (below 9th percentile)	17.4%	36.4%	.150

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. *Statistical significance using Bonferroni corrected alpha = .05 /3 = .017.

3.3.4.5 Driving Events

3.3.4.5.1 14-Day Driving Logs

Of the 1191 completed daily driving logs, participants reported driving on 77.8% of logs (*n* = 927 drives), with no significant differences in the number of completed drives (SW 75.6% vs DW 80.2%, *p* = .058). Overall, no between-groups differences existed for traffic conditions (*p* = .265), nor duration of drive with (SW *M* = 33.0 ± 23.4 min, vs DW *M* = 31.4 ± 19.4 min, *p* =.276).

Participants reported driving on a total of 550 day shifts (46.2%), 187 night shifts (15.7%), 14 afternoon shifts (1.2%), with 440 days off (36.9%). Driving purpose was comprised of 31.2% commuting to work; 28.7% commuting home; 12.3% errands (e.g., grocery store, appointment); 7.6% leisure or social outings; 4.3% family demands (e.g., driving children or caring for relatives); and 0.6% driving while on shift.

3.3.4.5.2 Subjective Sleepiness

Participants rated their subjective sleepiness using the Karolinska Sleepiness Scale (KSS) at three time points on each driving log (e.g., drive start, drive end, and maximum sleepiness experienced during drive). Mean KSS ratings are presented below in Table 3-13.

Overall, KSS scores for SW were significantly higher than DW in almost all circumstances and time points, as shown by the overall ratings comprised of all logged drives regardless of purpose, with higher ratings at all three time points (p <.001). Higher KSS was also noted at all time points for any shift commuting home (p <.001). SW also reported higher maximum and end-of-drive KSS scores when commuting both to and from work following day shift; and commuting to work for any shift; and at the end of a drive on days off. On just four occasions, there were no significant differences in sleepiness between groups, three being sleepiness at the start of the drive, and maximum sleepiness when driving on a day off.

Table 3-13 Subjective Sleepiness, by Shift and Drive Type

Shift (Drive Type)	Shiftworkers (SW) (*n* = 23)	Day Workers (DW) (*n* = 22)	Significance ($p \leq .017$*)
Overall, (all driving logs, types)	*M* ± *SD*	*M* ± *SD*	
KSS, Start	4.36 ± 1.87	3.68 ± 1.64	**<.001**
KSS, End	4.79 ± 2.53	3.68 ± 1.63	**<.001**
KSS, Maximum	5.15 ± 2.34	3.97 ± 1.72	**<.001**
Any Shift (commute to work)			
KSS, Start	4.35 ± 1.70	4.02 ± 1.71	.068
KSS, End	4.39 ± 1.99	3.81 ± 1.63	**.003**
KSS, Maximum	4.86 ± 2.10	4.20 ± 1.70	**.001**
Any Shift (commute to home)			
KSS, Start	4.73 ± 1.85	3.51 ± 1.63	**<.001**
KSS, End	5.71 ± 2.28	3.73 ±1.71	**<.001**
KSS, Maximum	5.98 ± 2.35	3.93 ±1.74	**<.001**
Day off (leisure, errand, social)			
KSS, Start	3.63 ± 1.91	3.34 ± 1.34	.221
KSS, End	4.00 ± 2.17	3.34 ± 1.52	**.016**
KSS, Maximum	4.35 ± 2.35	3.65 ± 1.64	.019
Day Shift (commute to work)			
KSS, Start	4.55 ± 1.68	4.04 ± 1.72	.022
KSS, End	4.65 ± 2.17	3.80 ± 1.61	**.002**
KSS, Maximum	5.23 ± 2.19	4.20 ± 1.71	**<.001**
Day Shift (commute to home)			
KSS, Start	3.75 ± 1.61	3.50 ± 1.64	.265
KSS, End	4.65 ± 2.06	3.71 ± 1.68	**<.001**
KSS, Maximum	4.87 ± 2.17	3.91 ± 1.75	**<.001**
Night Shift (commute to work)			
KSS, Start	4.19 ± 1.65	-	-
KSS, End	4.14 ± 1.79	-	-
KSS, Maximum	4.49 ± 1.94	-	-
Night Shift (commute to home)			
KSS, Start	5.83 ± 1.45	-	-
KSS, End	6.73 ± 1.99	-	-
KSS, Maximum	7.05 ± 1.99	-	-

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. *Statistical significance using Bonferroni corrected alpha = .05 /3 = .017

3.3.4.5.3 Severe Sleepiness, Nodding off, and Falling Asleep

Overall, SW reported a higher occurrence of severe sleepiness, nodding off, and/or falling asleep throughout the 14-day data collection period than DW, via both the percentage of logs and percentage of drivers recording these events from each group. Instances of severe sleepiness were determined via KSS ratings of 9/10, *"very sleepy, great effort to keep awake, fighting sleep" or 10/10, "very sleepy, can't keep awake"* at any point during a logged drive (start, end, or maximum rating). Instances of nodding off or falling asleep were directly coded in the driving log via a dichotomous yes/no selection. Overall, 34 drives were logged with a KSS of 9-10/10 indicating severe sleepiness, comprising 4% of the n = 927 recorded drives. However, SW logged a significantly larger number of drives with severe sleepiness on all drives (SW 6.8% vs DW 0.4%, χ^2= 26.748, df = 1, p <.001). Further, a greater percentage of SW reported one or more drive with severe sleepiness within the 14-day period (SW 52% vs DW 9%, p = .002).

Notably, 53% of drives with severe sleepiness occurred on night shifts, followed by 29% on day shifts and 18% on days off. Further analyzed by drive purpose, severe sleepiness most frequently occurred during: night shift - commute home (44% SW); day shift - commute to work (18% SW, versus 3% DW); day off - leisure/social (12% SW versus 3% DW). SW reported two instances each (6%) for day shift - commute to home, and night shift - commute to work; and one instance each (3%) for night shift - driving while on shift; day shift - leisure/social trip; or day off - driving for errands (3% SW). There were no instances of severe sleepiness during daily driving demands nor afternoon shift commutes. These events occurred across a range of traffic conditions (i.e., very busy to very quiet traffic), and did not significantly differ from traffic conditions for drivers with zero instances of severe sleepiness (p = .056). However, the duration of drives with instances of severe sleepiness were significantly longer (drives with reported severe sleepiness M = 37.6 ± 26.5 min, vs drives without M = 29.8 ± 18.4 min, $t(403)$ = -4.448, p <.001). Drivers logging any drive with severe sleepiness were significantly younger (M = 31.4 ± 8.2 years) than those who did not (M = 36.7 ± 10.8 years) (p <.001) and were more likely to be under the age of 30 years (60% with severe sleepiness, vs 32% without, χ^2 = 63.9, df = 1, p <.001). There were no sex-related differences in drivers logging any drive with severe sleepiness (71.4% female) versus those who did not (65.6% female).

Table 3-14 14-Day Sleep-Related Driving Events

Sleep-Related Driving Event	**Shiftworkers (SW)** (*n* = 23)	**Day Workers (DW)** (*n* = 22)	**Significance** ($p \leq .05$)
Severe Sleepiness, (KSS 9-10/10)			
Percent of logs	6.8%	0.4%	**<.001**
Percent of drivers	52.2%	9.1%	**.002**
Number of adverse events [a]	3.0 (1-8)	1.0 (1-1)	**.043**
Nodding off,			
Percent of logs	4.7%	1.1%	**.001**
Percent of drivers	39.1%	9.1%	**.019**
Fall Asleep,			
Percent of logs	0.5%	0.2%	1.00
Percent of drivers	8.7%	4.5%	.577

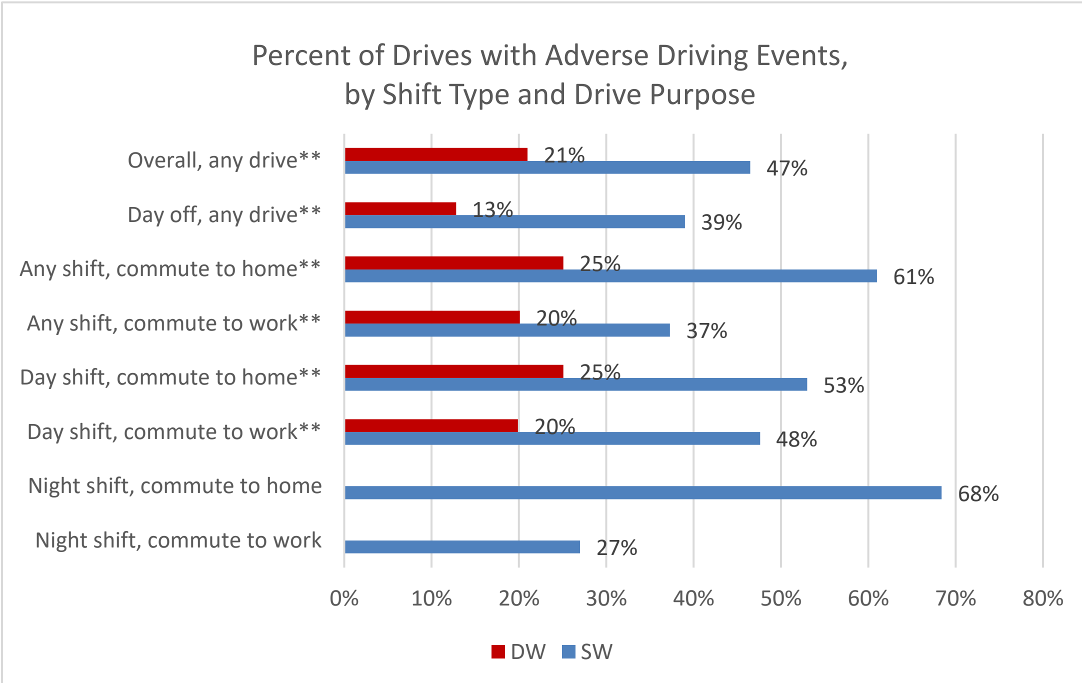
Note. Summary statistics include Median (Range) for continuous data, and percentages for categorical data. Significance level is set at $p < .05$. [a] = Independent Samples Mann-Whitney U Test

Critically, adverse driving events were reported in 100% of driving logs where participants reported severe sleepiness at any time point during the drive. Per each trip with severe sleepiness, SW reported a higher median number of adverse driving events (SW *Mdn* = 3, vs DW *Mdn* = 1.0, $U = 5.00$, $z = -2.004$, $p = .043$).

Overall, the adverse driving events most frequently reported during drives with severe sleepiness were: lack of awareness, as if driving on autopilot or a daze (67.6%); wandering into another lane (44.1%); memory gaps or unable to recall several kilometers (43.8%); rested their eyes while driving (26.5%); startling awake in the same lane (20.6%); ran onto the ‘rumble strips’ at the edge of the highway (14.7%). Adverse driving events are further characterized below for all drives.

3.3.4.5.4 Adverse Driving Events

The percent of drives reporting any adverse driving event is depicted by shift type and drive purpose in Figure 3-5, below. Notably, the highest percentage of drives with any adverse driving events occurred during commuting to home following night shift (68% SW). Overall – regardless of shift type or drive purpose – significantly more SW logged drives reporting any adverse driving event (SW 47% vs DW 21%, $p < .001$). Significant differences remained for this outcome on day shift, night shift, and day off, as well as commutes to and from work (all $p < .001$).

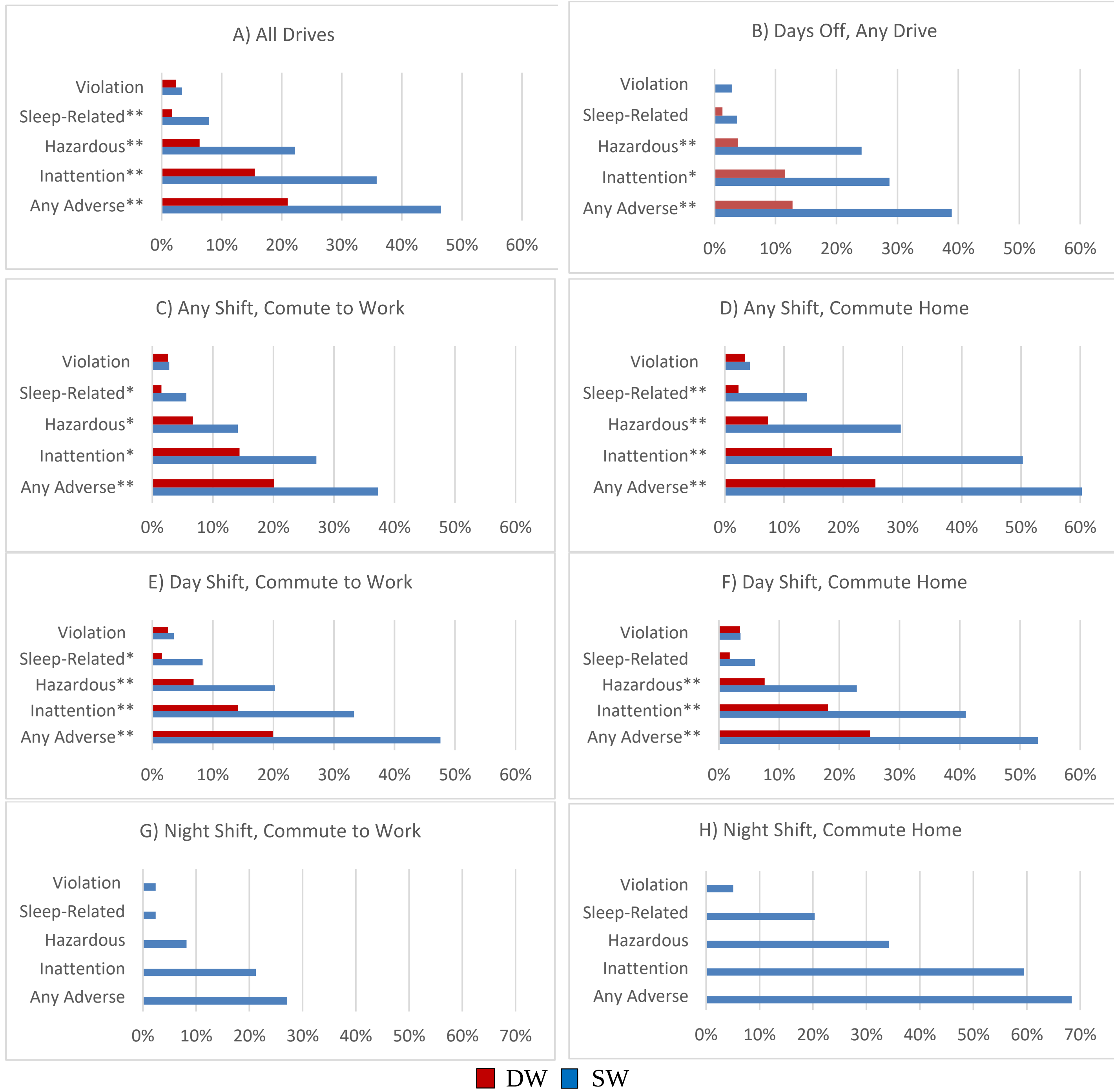


<u>*Notes:*</u> Signficant differences indicated by * $p \le .05$, **$p = \le .001$

Figure 3-5 Percent of Driving Logs with Adverse Driving Events

To further characterize adverse driving events over the 14-day period, adverse driving events are categorized as to whether they are sleep-related, inattention, hazardous, or violation events, to determine the primary types of driving events, and where between-groups differences may exist. Figure 3-6 (A- through H) depicts the percentage of driving logs reporting occurrences of adverse driving events, for (A) all drives – regardless of shift type or drive purpose, (B) days off – for any purpose, and for commutes to and from work for any shift (C, D), day shift (E, F), and night shift (G, H). As only SW provide night shift data, no between-groups differences are displayed for these drives.

As shown below in Figure 3-6 (A through H), the only category that did not show significant between-groups differences was Violation events. Significant between-groups differences are shown for Sleep-Related events in All Drives (A), Any Shift commuting to/from work (C, D) and Day shift commute to work (E), with no difference for day shift commute home (F). SW reported Any Adverse events, Hazardous events, and Inattention events significantly more often in all shift types and rive purposes (A-F).



Notes: Signficant differences indicated by * $p \leq .05$, ** $p = \leq .001$

Figure 3-6 Drives with Adverse Driving Events, By Shift Type and Drive Purpose

Detailed data for the percent of driving logs with adverse events, and the mean number of adverse events is detailed below in Table 3-15. Not only do SW have significantly higher rates of any adverse events on all shift types (i.e., day shift, night shift, day off), and all drive purposes (i.e., commute to and from work, or any drive purpose), but SW also report a higher mean number of adverse driving events during these drives (all *p* <.001).

Table 3-15 14-Day Summary of Adverse Driving Events

Total Number of Adverse Driving Events	**Shiftworkers (SW)** (n = 23)	**Day Workers (DW)** (n = 22)	**Significance** ($p \leq .017$*)
Overall (any shift),			
Adverse events, mean	1.02 ± 1.42	.34 ± 0.78	**<.001**
Logs with adverse events	46.5%	21.0%	**<.001**
Day Off, any drive			
Adverse events, mean	0.85 ± 1.32	0.22 ± 0.59	**<.001**
Logs with adverse events	38.9%	12.8%	**<.001**
Commute to work, any shift			
Adverse events, mean	0.67 ± 1.06	0.31 ± 0.72	**<.001**
Logs with adverse events	37.3%	20.1%	**<.001**
Commute to home, any shift			
Adverse events, mean	1.52 ± 1.69	0.42 ± 0.90	**<.001**
Logs with adverse events	61.2%	25.4%	**<.001**
Day Shift, commute to work			
Adverse events, mean	0.82 ± 1.07	0.31 ± .72	**<.001**
Logs with adverse events	47.6%	19.9%	**<.001**
Day Shift, Commute to home			
Adverse events, mean	1.06 ± 1.30	0.43 ± 0.91	**<.001**
Logs with adverse events	53.0%	25.1%	**<.001**
Night Shift, Commute to work			
Adverse events, mean	0.52 ± 1.05	-	-
Logs with adverse events	27.1%	-	-
Night Shift, Commute to home			
Adverse events, mean	1.91 ± 1.86	-	-
Logs with adverse events	68.4%	-	-

Note. Summary statistics include Median (Range) for continuous data, and percentages for categorical data.
*Statistical significance using Bonferroni corrected alpha = .05 /3 = .017.

3.3.4.5.5 1-Month Follow-Up Survey

In a survey administered 1-month after the prospective data collection, a significantly higher percentage of SW reported severe sleepiness episodes in the past month (SW 73.9% vs DW 31.9%, p = .005), along with a higher number of occurrences (SW *Mdn* = 2.0 vs DW *Mdn* = 0.0, U = 147.0, z = -2.549, p = .011). SW were significantly more likely to report nodding off (SW 30.4% vs DW 0%, p =.009), along with a higher number of occurrences (U = 176.0, z = 2.773, p = .006). While 13% of SW reported falling asleep in the past month (versus 0% of DW), neither percentage reporting nor number of occurrences were significant.

A higher percentage of SW reported adverse driving events (versus DW), in all domains except for violation events, as shown in Figure 3-7. No violation events were reported by either group in this time period.

Overall, significantly more SW reported any adverse driving event in the past month (SW 69.6% vs DW 22.7, p = .002). Significant differences were also reported for Inattention events (SW 56.5% vs DW 18.2%, p =.008); Hazard Hazardous (SW 52.2% vs DW 13.6%, p = .006), and Sleep-Related events (SW 39.1% vs DW 9.1%, p = .019).

Further, SW reported greater Any Adverse Driving events, via both the median types of any events and median occurrences of any adverse events (p =.001). Significant differences remained for the Sleep-Related, via types of events (p = .016) and occurrences of events (p = .007); Inattention events, via the number of types of events (p = .009) and occurrences of events (p = .007); and Hazard events via types (p = .004) and occurrences (p = .003) in the past month. There were no significant differences for Violations, as none were reported in the past month by either group.

Table 3-16 1-Month Follow up, Adverse and Sleep-Related Events

Driving Event Type	**Shiftworkers (SW)** (*n* = 23)	**Day Workers (DW)** (*n* = 23)	**Significance** ($p \leq .05$)
Sleep-Related Driving Events			
Severe sleepiness (KSS 9-10)			
Percent reporting	73.9%	31.8%	**.005**
Number of occurrences [a]	2.0 (0-5)	0.0 (0-10)	**.011**
Nodding off			
Percent reporting [b]	30.4%	0.0%	**.009**
Number of occurrences [a]	0.0 (0-3)	0.0 (0-0)	**.006**
Falling asleep			
Percent reporting	13.0%	0.0%	.233
Number of occurrences	0.0 (0-1)	0.0 (0-0)	.083
Adverse Driving Events			
Any Adverse Event			
Percent reporting	69.6%	22.7%	**.008**
Types of events	2.0 (0-7)	0.0 (0-3)	**.001**
Number of occurrences	2.0 (0-25)	0.0 (0-4)	**.001**
Sleep-Related Event			
Percent reporting	39.1%	9.1%	**.019**
Types of events	0.0 (0-3)	0.0 (0-1)	**.016**
Number of occurrences	0.0 (0-5)	0.0 (0-2)	**.007**
Inattention Event			
Percent reporting	56.5%	18.2%	**.008**
Types of events	1.0 (0-1)	0.0 (0-1)	**.009**
Number of occurrences	0.0 (0-15)	0.0 (0-3)	**.014**
Hazardous Event			
Percent reporting	52.2%	13.6%	**.006**
Types of events	1.0 (0-4)	0.0 (0-1)	**.004**
Number of occurrences	1.0 (0-10)	0.0 (0-2)	**.003**
Violation Event			
Percent reporting	0%	0%	—
Types of events	—	—	—
Number of occurrences	—	—	—

Note. Summary statistics include mean ± standard deviation (range) for continuous data and percentages for categorical data. [a] = Mann-Whitney U Test. [b] Fisher's Exact Test. Significance level is set at $p \leq .05$.

3.4 Discussion

This study examined the differences in sleep, sleepiness, and driving performance between healthcare SW versus DW. Findings supported the hypothesis that SW demonstrated lower sleep quality and quantity; higher levels of sleepiness while driving; and greater occurrence of sleep-related and adverse driving events in their 1-year history, as well as in a 14-day prospective trial and 1-month follow up survey. However, null findings failed to support hypotheses for 3-year driving record citations, self-report and proxy-report driving behaviours, driving habits and cognitive driving abilities.

First, findings of self-reported and objective actigraphy data showed that SW consistently demonstrate lower sleep quality and quantity than DW, both through overall shorter sleep quantity through the workweek, and significantly more SW obtaining severely insufficient sleep (<5h/24h). Critically, 22.5% of SW logs documented TST below this threshold (versus 7.5% of DW, $p < .001$). SW were also found to have significantly lower self-reported sleep quality (PSQI), with 95.7% of SW group categorized as poor sleep quality. The prevalence of poor sleep quality in this study sample is higher than published estimates, which indicate 65 to 78% of nurses on rotating shifts have poor quality sleep on the PSQI (McDowall et al., 2017; Zeng et al., 2020). The higher prevalence in this study compared to existing data may be related to the COVID-19 pandemic, or the mixed nature of the participant group (i.e., nurses and paramedics). SW also showed higher risk for sleep apnea (STOP-Bang), and lower objective sleep quality (SE) via 14-day actigraphy. While there were no significant differences in chronic daytime sleepiness (ESS), SW consistently identified higher ratings of state sleepiness (KSS) when driving overall (i.e., all shift types and drive purposes), and at the end of drive. SW also identified higher ratings of maximum sleepiness during the drive, with mixed results for sleepiness at the start of drives. Combined, SW’s overall lower subjective and objective sleep quantity and sleep quality, and higher subjective state sleepiness while driving (versus DW) shows consistent patterns with concerning implications. These data indicate that not only are SW obtaining lower sleep quantity, they are significantly more likely to obtain sleep quantity below thresholds at which impaired driving performance would be demonstrated by *“most healthy drivers”* (Czeisler et al., 2016) or the *“vast majority of drivers”* (Dawson et al., 2021). Further, consistently higher subjective sleepiness ratings during driving is a *possible* predictor of adverse driving outcomes (Knott et al., 2020). Given an estimated 49,255 nurses and 7,440 paramedics currently employed in shiftwork in Ontario, and our findings that 22.5% of SW sleep logs are <5h/24h sleep within a 14-day period, approximately 12,749 healthcare workers are potentially driving impaired because of severely insufficient sleep in a 14-day period. If such projections were to be empirically validated, this would indicate a severe impact of a modifiable factor on a substantial proportion of workers.

Study findings support the hypothesis that SW demonstrated a greater occurrence of sleep-related and adverse driving events in the past 1-year, as well as during the 14-day prospective data collection period and 1-month follow-up survey. Significantly more SW (versus DW) reported a 1-year history for occurrences of severe sleepiness (SW 91.3%, vs DW 34.8%, p <.001), nodding off (SW 69.6% vs DW 17.4%, p = .003), or falling asleep (SW 26.1%, vs DW 4.3%, p = .040). Notably, the percentage of SW reporting nodding off (60.9%) or falling asleep (26.1%) in the past year is also starkly higher than reported by Canadian drivers in general (14.5%) (Vanlaar et al., 2008). This highlights the at-risk nature of this group of drivers for sleep-related driving events. Further, in the past 1-year a significantly higher percentage of SW (95.5%) (versus DW, 45.5%, p <.001) reported any adverse driving event as well as sleep-related, inattention and hazardous events; a higher number of types of adverse events; and higher total number of occurrences of adverse events. There were no differences in violation events.

Notably, differences in self-reported 1-year driving history remained consistent for driving events reported during the 14-day prospective data collection period and the 1-month follow up survey for severe sleepiness, nodding off, falling asleep, and adverse driving events. SW consistently demonstrated a significantly higher number of occurrences of severe sleepiness or nodding off (vs DW); a greater percentage of SW reported any adverse events; a greater number of types of adverse events; and a greater number of occurrences of events. However, no differences were found with respect to occurrences of falling asleep or for violation events. Given these are more severe and rare events, a larger sample size or a longer period of observation may be required to detect. During the 14-day period, all drives with any episode of severe sleepiness also documented adverse driving events; and the drivers reporting any episode of severe sleepiness were identified as significantly younger than drivers who did not and were majority SW (SW 52% vs DW 9%). Taken together, these patterns of severe sleepiness, nodding off, and adverse driving events in a 1-year history, as well as prospective data collection demonstrate the functional impacts on driving performance, and highlight healthcare SW as an at-risk group.

Study findings failed to support the hypothesis that SW would demonstrate poorer driving records, driving behaviours, cognitive driving abilities, and driving habits. No significant between-group differences were found for 3-year driving record citations; self-rated and proxy-rated driving behaviour scales (DBQ, FTDS); cognitive driving abilities (OTMT-A, OTMT-B, O-SDMT); nor driving habits via the SDFB subscales. While SW were significantly more likely than DW to continue driving after noticing symptoms of sleepiness at the start of the study, these differences were no longer significant at the 1-month follow up. Notably, the SW scores decreased over time and DW scores remained consistent. Future research may examine whether a learning effect exists as a result of increased awareness with event tracking, which may decrease the frequency of continuing to drive after noticing sleepiness. It is possible that the effect sizes for these outcomes were smaller than this study was powered to detect, or, that no true differences exist. Future research may consider a larger sample size, integrating the evaluation of a driving rehabilitation therapist in addition to the self- and proxy-report tools, and using an expanded clinical assessment of cognitive driving abilities, beyond what is possible via a telephone screening.

3.4.1 Limitations

This work has limitations. Since this study occurred during the COVID-19 pandemic, additional pressures may exist due to documented staffing shortages within Ontario or work/life demands on participants (Hassan, 2022; Porter, 2022). While representative of the current Canadian healthcare system, our findings may not be representative of pressures on healthcare workers in other jurisdictions, and as such the effects shown in this study may be larger than observed in other settings. Due to technological errors, not all subscales for the SFDB were available for analysis. As such future research may consider including this tool, even though there were no significant differences in the available subscales in this study. Finally, cognitive screening tools used in this study were limited to those validated to oral telephone administration; and future studies may consider including other modes of assessment (e.g., tablet-based, videoconferencing or in-person) to expand the content of a cognitive screening. Given the breadth of the research objectives in examining sleep, sleepiness and driving performance, multiple comparisons were computed in data analysis, increasing the risk of a Type I error (Portney & Watkins, 2009). To mitigate this risk, Bonferroni adjusted alpha levels were used where dependent variables were subject to more than two analyses. The conservative nature of this adjustment results in reduced statistical power to detect differences where one may exist (Portney & Watkins, 2009).

3.4.2 Strengths

This work has several strengths. The findings of this study build on existing research demonstrating increased subjective sleepiness and adverse driving events in post-shift drives (versus pre-shift drives) in select homogeneous participant groups (e.g., nurses working permanent nights, rotating shifts, or physician trainees alternating 24h extended and dayshifts) (Anderson et al., 2018; Mulhull et al., 2019). This study was conducted remotely during the COVID-19 pandemic, and thus engaged healthcare SW from across Southwestern Ontario, enabling a broader range of participants working for various employers and driving in diverse naturalistic settings. Participant groups were comprised largely of groups historically under-represented in research on shiftwork and driving performance (e.g., healthcare workers, women, younger workers, and those not in full-time roles). Healthcare worker participants were employed in a broad range of occupations representative of typical healthcare sector (e.g., nursing, paramedicine, allied health, and other healthcare staff including support staff, technicians and management); were majority female (72%); and ranged from 21-58 years of age. Participants had a mean of 10.4 years' work experience (R = 1-24 years) and were employed in either traditional full-time positions (87%) or worked full-time equivalent hours via alternative arrangements (13%), thus enabling younger workers and those with less seniority to participate. Increasing the scope of participant representation via occupation, employment status, age and sex aids in addressing limitations in existing research through survivor cohort and selection bias. To advance the understanding of driving performance more broadly, outcome measures focusing on multiple facets of driving performance (e.g., history, habits, behaviours, abilities, events) were included. Further, multiple modes of data were collected over several time points and included both self-report and proxy-report data, objective driving records, sleep data, and cognitive screening. To enhance the reliability, validity, and completeness of data, participants were provided with instructions on the use and care of the Actiwatch sleep watch, support to answer questions, and scheduled reminders to complete tools. Research assistants were trained in data interpretation and scoring, and all data was validated by the PhD Candidate prior to analysis to ensure accuracy.

3.4.3 Implications

The findings in this study demonstrate that healthcare SW (versus DW) are a significantly at-risk group of drivers, on the basis of reduced sleep quantity overall, with 39% of SW sleep logs at <6h/24h indicating mild insufficient sleep, at a level where functional and cognitive deficits accrue; with 22.5% of sleep logs at <5h/24h, suggesting severely insufficient sleep proposed as consistently resulting in functional performance equivalent to impaired driving due to alcohol (Dawson et al., 2021). Together with the consistently higher subjective sleepiness ratings (KSS), increased rates of severe sleepiness, nodding off, and adverse driving events (i.e., sleep-related, inattention, and hazardous events) across a 1-year history, 14-day prospective data collection period, and 1-month follow up survey, this demonstrates a consistent pattern that is worthy of further investigation. Further, preliminary analysis suggests that younger drivers were more likely to report episodes of severe sleepiness in the 14-day period. Specifically, future research should aim to identify factors (e.g., demographic, sleep-related, or driving history) that may predict at-risk drivers who report the greatest number of adverse driving events. This research may aid in identifying SW who may be at risk and may benefit from intervention, and inform the development of future interventions, education, clinical or policy-driven approaches to mitigate risks faced by SW.

Finally, the results of this study show that 12h rotating shifts in healthcare have demonstrably negative impacts on healthcare SW sleep quantity and quality, sleepiness, and adverse driving events across multiple time points. These effects have also been shown in studies of healthcare workers on >24h shifts (Anderson et al., 2018), 12h rotating day, evening, and night shifts (Mulhull et al., 2019), and permanent 12h night shifts (Ftouni et al., 2013), and in overnight shifts being a likely predictor of adverse driving performance (Knott et al., 2020). Future research may investigate whether the use of shorter rotating shifts (e.g., 10h) may mitigate some of these negative impacts, and improve sleep quantity, quality, and reduce the frequency of severe sleepiness, nodding off, and/or other adverse driving events. Indeed, the Canadian Nursing Association recommendations include reconsidering high reliance on 12h shifts in favor of shorter shifts or staff choice in shift length, in order to support work-life balance and safety (Canadian Nurses Association, 2010). While this work pertains directly to driving, the impact of poor sleep quality, quantity, and sleepiness also has important implications in other aspects of healthcare worker safety and patient safety; and using the data form this study may inform not only future driving studies but have the potential for improved working and safety conditions broadly (Canadian Nurses Association, 2010).

3.5 Conclusion

This study examined within-subjects differences in the sleep, sleepiness, and driving performance of healthcare SW working 12h rotating day/night shifts compared to healthcare DW working regular day shifts. Healthcare SW, compared to DW, show overall significantly lower sleep quantity, sleep quality, and increased occurrences of severe sleepiness, nodding off, and adverse driving events (i.e., sleep-related, inattention, and hazardous events). Findings remain consistent via self-reported history at the intake survey, during the 14-day prospective data collection period, and at the 1-month follow-up survey. Findings regarding driving habits were mixed, with SW significantly more frequently continuing to drive after noticing signs of sleepiness at the study intake, but no difference in frequency at the 1-month follow-up. No differences were identified via self-or proxy-reported driving behaviours, citations on 3-year driving records, nor in cognitive skills underlying driving abilities during a telephone-based cognitive screening assessment. Future research may further investigate factors that may predict SW who are most at risk of adverse driving events to inform the development of potential future interventions in this population. Additionally, future research may examine whether shorter shift durations mitigate some of the impacts on sleep, sleepiness, and driving performance outcomes in this population. This research has important implications for healthcare worker education and training, workplace policy, and clinical practice for occupational therapists, driving rehabilitation, occupational and sleep medicine providers.

3.6 References

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Chapter 4

4 Correlations and Predictions Adverse Driving Events in Healthcare Workers[1]

Shiftwork (e.g., rotating day/night shifts) is commonly required in the healthcare sector, impacting 45% of all employees, and up to 80% of occupations like paramedicine (Fischer & MacPhee, 2017; Williams, 2008). Importantly, shiftwork has been shown to decrease sleep quantity, sleep quality, and increase subjective sleepiness (Akerstedt & Wright, 2009). Results from the prior study (Chapter 3, pages 63-120) show that healthcare shiftworkers (SW) compared to dayworkers (DW) demonstrate significant differences related to sleep quantity, quality, and subjective sleepiness while driving and driving performance outcomes. However, specific relationships between healthcare worker demographic, sleep, sleepiness, and driving performance indicators on the sum of adverse driving events in the future are not yet established. Identifying and quantifying indicators that may predict future adverse driving events may aid in the future development of screening for at-risk workers, and the development of interventions, education, and policy to mitigate risks associated with shiftwork on driving performance.

Insufficient sleep is a known significant risk factor for motor vehicle collisions (MVC) (Czeisler et al., 2016), with risk quantified via the sleep quantity in the past 24h. The vast majority of drivers demonstrate driving performance impairments equivalent to alcohol impairment with ≤5h/24h sleep (Dawson et al., 2021), and would be unfit to operate a motor vehicle with <2h/24h sleep (Czeisler et al., 2016). Performance impairments arise from neurocognitive and neurobehavioural deficits, with those who obtain the least amount of sleep demonstrating the greatest cognitive impairment (Banks et al., 2017), many of which are in key areas required for driving (Barco et al., 2012). While repeated (i.e., chronic) exposure to insufficient sleep is known to increase functional impairments in a dose-dependent manner (Banks et al., 2017), most existing research on driving performance outcomes in SWs focuses comparing performance following a single shift (Knott et al., 2020). As such, it is unknown whether sleep quantity over

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[1] A version of this manuscript is in preparation for submission to the journal *Accident Analysis and Prevention*.

longer time periods may predict adverse driving outcomes, and predictive validity of sleep quality measures is not yet established.

Similarly, increased subjective sleepiness occurs with insufficient sleep, and is shown to peak at the end of overnight shifts (i.e., before driving home from work), and toward the end of workweek in nurses (Geiger-Brown et al., 2012). Increased subjective sleepiness via the Karolinska Sleepiness Scale (KSS) score (Akerstedt & Gillberg, 1990) while driving has been shown to possibly predict adverse driving outcomes (Knott et al., 2020). Moreover, increased pre-drive KSS has been associated with sleep-related driving events following night or extended duration (≥24h) shifts (Anderson et al., 2018; Ftouni et al., 2013). Each point higher on KSS pre-drive, predicts a 2.39 increased odds of sleep-related adverse events, with a KSS ≥6/10 correctly predicting the occurrence of sleep-related adverse events on the drive with 91% sensitivity (versus 69% specificity for predicting no sleep-related events) (Anderson et al., 2018). However, it is unknown if average KSS over a longer period (e.g., weeks) may be associated with future occurrence adverse driving events. Elevated levels of chronic daytime sleepiness, via the Epworth Sleepiness Scale (ESS) score (Johns, 1991), have been shown to predict an increased future risk for near-miss MVC in the general population (Powell et al., 2007); however, data specific to SW is unknown.

In the general population, certain driving performance outcomes may predict future adverse driving outcomes, such as near-miss or actual MVC, or driving record citations. Drivers reporting a history of ≥4 sleep-related near-miss MVCs (versus zero) have an 1.89 times elevated risk for future MVC (Powell et al., 2007). Further, drivers self-reporting elevated risky driving behaviours via the Driving Behaviour Questionnaire (DBQ) average score (Reason et al., 1990) predicts self-reported citations and crashes, in both prospective and retrospective studies (de Winter & Dodou, 2010).

In addition to shiftwork, demographic factors such as sex, age, and parental status are known risk factors for sleep-related MVC (Thomas et al., 2021). Road traffic injuries are a global leading cause of death for younger adults <29 years, the majority of whom are male (World Health Organization, 2022). Yet, research on SW driving performance has historically excluded participants <24 years of age, and insufficient evidence exists regarding whether male sex may predict adverse driving events (Knott et al., 2020). However, younger drivers demonstrate greater vulnerability to insufficient sleep with greater deterioration of driving performance under conditions of insufficient sleep (versus older drivers), which may be attributed to brain maturation, lifestyle factors, driving experience, and ability to self-regulate driving (Cai et al., 2021; Scarpelli et al., 2021; Soleimanloo et al., 2017).

Results from Chapter 3 specifically show that healthcare SW (versus DW) demonstrated significantly shorter overall sleep via self-report (p = .021) and objective actigraphy (p = .036); more frequent occurrence of insufficient sleep (p <.001); and poorer sleep quality via self-report (p = .004) and objective actigraphy (p = .001). Further, SW (versus DW) reported significantly higher overall subjective sleepiness while driving (p = <.001) and reported more frequently continuing to drive after noticing signs of sleepiness (p = .007). Finally, SW reported a significantly higher occurrence of adverse driving events (e.g., sleep-related, inattention, hazardous, violation events) in their 1-year driving history (p <.001), a 14-day prospective data collection period (p = <.001), and 1-month follow-up survey (p = .008).

To build on existing research and address gaps in knowledge, this study will examine relationships between healthcare worker demographics, sleep, sleepiness, and driving performance outcomes with the total sum of adverse driving events reported in a 6-week period.

4.1.1 Objective

The objective of this study is to determine correlations and predictive validity of demographic, sleep-related, and driving performance-related indicators (independent variables) on the 6-week sum of self-reported adverse driving events (dependent variable) in healthcare workers. This objective was achieved via two specific aims: (1) examine the strength, direction, and significance of associations between the independent and dependent variables; (2) compute a multiple linear regression to determine significant predictors of the 6-week sum of adverse events.

4.1.2 Hypotheses

We hypothesized that a higher 6-week sum of adverse driving events (dependent variable) would be associated with the following independent variables: lower overall sleep quantity and quality, higher subjective sleepiness, higher 1-year history sum of adverse driving events, poorer driving behaviour, poorer cognitive driving ability, younger age, and male sex.

4.2 Methods

The Health Sciences Research Ethics Board at Western University approved this study (ID# 116473; see *Appendix C* for the approval letter).

4.2.1 Design

This study used a between-group design, as outlined in Chapter 3. Participants were comprised of 50 healthcare including shiftworkers on rotating day/night 12h shifts (SW; $n = 25$) and dayworkers (DW; $n = 25$). Additional data were provided by proxy-raters (e.g., friend, family member, coworker, $n = 50$) invited by healthcare worker participants. As a token of appreciation, healthcare workers received a gift card ($25), while proxy-raters could enter a draw for one of four $10 gift cards.

Using a two-tailed $\alpha = .05$ and $\beta = .20$, a sample size of $n = 36$ is required to detect a correlation of $r = 0.45$ (Browner et al., 2013).

4.2.2 Procedure

The study setting, participant recruitment, consent, eligibility criteria, data collection and data management procedures were conducted as detailed in the prior study (Chapter 3, pages 69-82). Additionally, participants were excluded from this study if they did not complete the 14-day driving logs and/or 1-month follow-up survey (e.g., mid-study participant withdrawal), as these data points were required to calculate the dependent variable.

4.2.3 Measures

The 6-week sum of adverse driving events (dependent variable) was calculated using the sum of the total number of adverse driving events documented in the twice-daily 14-day driving logs (maximum of 28 drives) combined with the 1-month follow-up survey. Adverse driving events included Sleep-related, Inattention, Hazardous, and Violation events, as outlined in Chapter 3 (pages 81-82). Independent variables of interest were comprised of demographic, sleep-related, and driving performance-related variables presented in Chapter 3 (pages 69-80).

Demographic variables included age, sex, number of shifts worked in the past month, number of overtime shifts in the past month, or longest shift in the past month. Sleep-related variables included both subjective and objective sleep quantity and quality. Subjective sleep quantity was measured via self-reported average sleep quantity past work week (hours). Objective sleep quantity was captured via four variables calculated to summarize the 14-day actigraphy data into single data points to quantify and describe total sleep time (TST) trends. These include the TST minimum – 14-day (e.g., shortest duration of sleep captured in a single 24h period during the 14-days), TST Average 14-day (e.g., average duration of sleep per 24h in the 14-day period), as well as a Percent of 14-day TST <6h/24h or <5h/24h, to quantify how frequently participants may experience insufficient sleep. Sleep quality was captured via self-report questionnaires, Pittsburg Sleep Quality Index, PSQI (Buysse et al., 1989) and STOP-Bang (Chung et al., 2008). Objective sleep quality was captured via sleep efficiency (SE) actigraphy output, (e.g., average SE per 24h in the 14-day period).

Sleepiness was quantified via the Epworth Sleepiness Scale (ESS) (Johns, 1991), a standardized questionnaire for daytime sleepiness . Subjective sleepiness while driving was captured via the Karolinska Sleepiness Scale, KSS (Akerstedt et al., 2017) which was self-reported at the start and end of each drive, as well as the maximum experienced during the drive. These data points were submitted twice-daily via driving logs over 14-days, for a possible maximum of 28 logs per participant. The calculated summary variables included an KSS Maximum – 14-day average (average of the maximum KSS rating for all drives submitted during the 14-day period), and KSS Overall – 14-day Average (e.g., average KSS rating for each drive, across all 14-days). Finally, person-related factors that can influence sleep and sleepiness included the revised Morningness and Eveningness Questionnaire (rMEQ) (Adan & Almirall, 1991), Work-Family Conflict Scales for Time and Strain (WFC-Time, WFC-Strain) (Carlson et al., 2000), and parental status to dependents <18 years.

Driving performance variables considered driving history, habits, behaviour, and cognitive driving ability. Driving history was quantified via self-reported 1-year sum of adverse driving events; kilometers driven per year; commute time; and whether participants vehicles were equipped with in-vehicle information systems (IVIS) or advanced driver assistance systems (ADAS). Driving habits were quantified via how frequently participants indicated continuing to drive after noticing signs of sleepiness (e.g., from 1 = never to 10 = frequently). Driving behaviours were quantified via self-report standardized questionnaire on risky driving habits, the Driving Behaviour Questionnaire, DBQ (Cordazzo et al., 2016), and via proxy-report standardized questionnaire, the 21-item Fitness-to-Drive Screening Measure, FTDS (Classen et al., 2018). Finally, cognitive driving ability was quantified via *z*-scores on the Oral Trail Making Test A and B (OTMT-A, OTMT-B), and the Oral Symbol Digits Modalities Test (O-SDMT).

Table 4-1, below, identifies independent variables by domain, and whether significant differences between shiftworker and dayworker groups were found for these variables in the prior study. To protect against Type I errors arising from multiple comparisons, Bonferroni adjusted alpha levels were used to identify statistically significant results where greater than two analyses were completed on the same dependent variable (Portney & Watkins, 2009b). The adjusted alpha level was computed by α/c, where c = number of tests (Portney & Watkins, 2009).

Table 4-1 Independent Variables, by Type and Significance

Type	*Variable*	*Significant*
Group	Group	X
Demographic	Age	X
	Sex	
	Number of shifts, past month	X
	Longest shift length, past month	X
	Number of overtime shifts, past month	
Sleep Quantity	Self-Report Average Sleep, Past Workweek	X
	TST Minimum, 14-day	
	TST Average, 14-day	X
	Percent of 14-day TST <6h/24h	X
	Percent of 14-day TST <5h/24h	X
Sleep Quality	PSQI Score	X
	STOP-Bang	X
	SE, 14-day Avg	X
Sleepiness	ESS Score	
	KSS Maximum, 14-day Avg	X
	KSS Overall, 14-day Avg	X
Person Factors	rMEQ score	X
	WFC Time score	X
	WFC Strain score	X
	Parental Status (<18 year)	
Driving History	1-Year sum adverse events	X
	Kilometers Driven per year	
	Commute Time	
	Vehicle with IVIS technology	
	Vehicle with ADAS technology	
Driving Habit	Continue to drive after sleepiness	X
Driving Behaviour	DBQ Full Scale, average	
	FTDS Score	
Driving Ability	OTMT-A, *z*-score	
	OTMT B, *z*-score	
	O-SDMT, *z*-score	

Notes: TST = Total Sleep Time, rMEQ = revised Morninginess and Eveningness Questionnaire, WFC Time = Work-to-Family Conflict, Time, WFC Strain = Work-to-Family Strain, PSQI = Pittsburg Sleep Quality Index Scale, SE = Sleep Efficiency, ESS = Epworth Sleepiness Scale, KSS = Karolinska Sleepiness Scale, DBQ = Driving Behaviour Questionnaire, FTDS = Fitness-to-Drive Screening Measure, OTMT-A = Oral Trail Making Test – A, OTMT-B = Oral Trail Making Test- B, OSDMT = Oral Symbol Digits Modalities Test. Significance level is set at $p < .05$.

4.2.4 Data Analysis

The statistical analysis was completed using IBM SPSS Statistics (Version 29, IBM Corporation, 2022). The data analysis plan was reviewed in consultation with a statistician.

Bivariate correlations were calculated to examine the strength and association between the dependent variable (the total sum of adverse driving events over a 6-week period) and the independent variables outlined above. Outliers were detected via inspection of a boxplot, with one case removed as an outlier on the dependent variable. Scatterplots were visually examined for a linear relationship; homogeneity of variances was examined using Levene's test for equality of variances, and normality was examined using Shapiro-Wilk's test (p >.05). Bivariate correlations between the dependent variable (sum of adverse events) and independent variables with continuous data (e.g., age, PSQI score, TST) were examined using Pearson's correlations (r) if all assumptions were met. Predictors not meeting these assumptions (e.g., non-normal data) were examined using Spearman's Rho (r_s), a non-parametric alternative. Bivariate correlations with dichotomous independent variables (e.g., group, sex) were assessed using Kendall's tau-b (τ_b) as a non-parametric alternative to Pearson's correlations. A point-biserial correlation was used due to violations in one or more of homogeneity of variances, and/or normality. The strength of association between the independent and dependent variables were considered as little to no relationship (r <.25), fair relationship (r =.25-0.49), moderate to good relationship (r = 0.50-0.74), and good to excellent relationship (r ≥.75) (Portney & Watkins, 2009a).

Independent variables with significant (p ≤.05) bivariate correlations with the dependent variable were then examined for inclusion in a linear regression model. To address multicollinearity, bivariate correlations between independent variables were calculated, and independent variables with intercorrelations of r >0.50 were examined for removal (Leech et al., 2011). A backward stepwise linear regression was then used to identify possible predictors of the sum of adverse driving events reported in a 6-week period. All remaining variables were added to the model, and at each step variables were removed if p >0.1, until the remaining predictor variables all had p <0.1. After initial review, two additional cases were removed as outliers, with one case showing studentized deleted residuals (> ± 3 SD), and a second case exceeding thresholds for Cooks Distance (> 1.0), and Leverage values (>0.5) (Stevens, 2011), resulting in 41 cases included in the final model. Assumptions for linear regression were examined and met. Linear relationships were observed between the independent and dependent variables via inspection of scatterplots; and independence of residuals via Durbin Watson (0.273); and homogeneity of variances was demonstrated via a visual inspection of a plot of studentized residuals versus unstandardized predicted values. No further concerns were identified for multicollinearity via tolerance values (<0.1) nor intercorrelations of >0.5 between independent variables. No further outlier points were identified, and the assumption of normality was met via inspection of a Q-Q plot.

4.3 Results

4.3.1 Participants

Participant flow and overall characteristics of the participants are outlined in Chapter 3 (Figure 3-2, page 93). Fifty-one healthcare worker participants consented for this study, with 45 participants completing all study procedures. Data analysis for this study is based on the 45 participants (SW = 23, DW = 22) who completed the study procedures, including the 14-day driving logs and 1-month follow-up survey. Overall, SW participants were $M = 36.0 \pm 12.1$ years of age (R = 21-58) and 65.2% female, and DW participants were $M = 34.7 \pm 9.0$ years of age (R = 26-56), and 77.3% female. There were no significant differences between SW and DW age (p = .693) nor sex (p = .288).

4.3.2 Correlations

Table 4-2 details the bivariate correlations between the independent variables and the 6-week sum of adverse driving events. Significant correlations with moderate to good relationship (r = 0.50 - 0.74) between independent and dependent variables were identified for just three independent variables: participant age, TST 14-day-minimum, and KSS maximum 14-day average. An additional 14 independent variables were identified with significant correlations, with a fair relationship (r =.25 - 0.49) between the dependent and independent variables.

Participant demographic characteristics included significant association with a moderate to good negative relationship between age and the 6-week sum of adverse events (r_s = -.576, p <.001). Significant associations with fair relationships were shown for Group (SW or DW) (τ_b = -.484, p = <.001), and the longest shift worked in the past month (r_s = .324, p = .041).

For sleep quantity, significant associations with a moderate to good positive relationship were found for TST minimum, 14-day (r = -.571, p <.001), and with a fair positive relationship for percent of 14-day sleep logs with <6h/24h sleep (r_s = .313, p =.038). For sleep quality, significant associations were found for PSQI score (r =.431, p = .005), and SE 14-day average (r_s = -.380, p =.016). For sleepiness, all significant relationships were found with a positive moderate to good relationship for KSS maximum rating, 14-day average (r = .533, p = <.001), and positive fair relationships for ESS Scores (r = .414, p = .007) and KSS overall 14-day average (r = .499, p = <.001). Person factors with significant associations showed fair positive relationships for rMEQ score for chronotype (r = -.373, p =.016), and Work-Family Conflict (WFC) Time (r =.457, p = .003), and Strain (r = .398, p = .010).

Driving performance indicators (e.g., driving history, habits, behaviours, and abilities) showed significant associations, with fair positive relationships for the past 1-year sum of adverse events (r_s = .329, p = .036), likelihood of continuing to drive after noticing sleepiness (r_s = .369, p = .018), DBQ Full Scale average score (r = .324, p = .039), and a fair negative relationships for the OTMT-A *z*-score (r_s = -.360, p = .021).

Table 4-2 Bivariate Correlations with 6-week Sum of Adverse Driving Events

Domain	*Independent Variable*	*Correlation coefficient*	*Significance*
Group	Group[a]	**-.484**	**<.001**
Demographic	Age[b]	**-.576**	**<.001**
	Sex[a]	.143	.282
	Number of shifts, past month[b]	-.194	.224
	Longest shift length, past month[b]	**.324**	**.041**
	Number of overtime shifts, past month	.160	.316
Sleep Quantity	Self-Report Average Sleep, Past Workweek	-.241	.152
	TST Minimum, 14-day Avg	**-.571**	**<.001**
	TST Maximum, 14-day Avg	.296	.064
	TST Average, 14-day	-.145	.372
	Percent of 14-day TST <6h/24h[b]	**.313**	**.038**
	Percent of 14-day TST <5h/24h	.269	.077
Sleep Quality	PSQI Score	**.431**	**.005**
	STOP-Bang[b]	.094	.557
	SE, 14-day Avg[b]	**-.380**	**.016**
Sleepiness	ESS Score	**.414**	**.007**
	KSS Maximum, 14-day Avg	**.533**	**<.001**
	KSS Overall, 14-day Avg	**.499**	**<.001**
Person Factors	rMEQ score	**-.373**	**.016**
	WFC Time score	**.457**	**.003**
	WFC Strain score[b]	**.398**	**.010**
	Parental Status (<18 year) [a]	-.091	.495
Driving History	1-Year sum adverse events[b]	**.329**	**.036**
	Kilometers Driven per year (100's) [b]	.068	.679
	Commute Time	.170	.295
	Vehicle with IVIS technology [a]	-.156	.239
	Vehicle with ADAS technology [a]	-.131	.323
Driving Habit	Continue to drive after sleepiness[b]	**.369**	**.018**
Driving Behaviour	DBQ Full Scale, average	**.324**	**.039**
	FTDS Score	-.262	.123
Driving Ability	OTMT-A, *z*-score[b]	**-.360**	**.021**
	OTMT B, *z*-score[b]	.033	.810
	OSDMT, *z*-score	.051	.752

Notes: Correlation coefficients are Pearson's (r), unless [a] = Kendall's Tau-b, [b]= Spearman rho. Significance, *p* = <.05. TST = Total Sleep Time, rMEQ = revised Morninginess and Eveningness Questionnaire, WFC Time = Work-to-Family Conflict, Time, WFC Strain = Work-to-Family Strain, PSQI = Pittsburg Sleep Quality Index Scale, SE = Sleep Efficiency, ESS = Epworth Sleepiness Scale, KSS = Karolinska Sleepiness Scale, DBQ = Driving Behaviour Questionnaire, FTDS = Fitness-to-Drive Screening Measure, OTMT-A = Oral Trail Making Test – A, OTMT-B = Oral Trail Making Test- B, OSDMT = Oral Symbol Digits Modalities Test.

4.3.3 Regression

The 17 significant bivariate correlations between independent variables and the dependent variable outlined above were examined for inclusion in a multiple regression. To address multicollinearity between independent variables, bivariate correlations were computed and examined for intercorrelations of r >0.50. *Appendix G* presents the bivariate correlation matrix for independent variables. Six independent variables were removed due to high intercorrelations: the longest shift in the past month; TST minimum 14- day; KSS Average 14-Day; rMEQ Score; WFC Time; and WFC Strain. The remaining 11 independent variables were entered into a multiple regression using a backward variable selection model. Table 4-1 details the regression coefficients and standard for the initial and final model. A full table detailing each model iteration (Models 1-8) is included in *Appendix H*. Assumptions for multiple regression were examined and met, with significant outliers or influential cases removed.

The resulting multiple regression model included Age, Group, PSQI score (i.e., sleep quality) and percent of sleep logs with <6h/24h sleep in the 14-day period. The model significantly predicted the total number of adverse driving events reported in a 6-week period, $F(4,36) = 35.924$, $p < .001$. All four variables significantly added to the prediction ($p < .05$). The final model was determined to be a good fit for the data, with a multiple correlation coefficient $R = 0.894$, showing a good to excellent relationship. The total variation is explained by the coefficient of determination ($R^2 = .800$) suggesting that in this sample, the model explains 80% of the variation in the dependent variable. Considering the Adjusted coefficient of determination ($\Delta R^2 = .777$), the model continues to show a good fit, explaining 77.7% of the variation in the dependent variable expected at the population level. The ΔR^2 estimates a large effect size (Cohen, 1988). Examining partial correlations, Age explains 61.5% ($r = -.784$) Group membership 41.5% ($r = -.644$), PSQI Score 27.7% ($r = .526$), and percentage of days with sleep <6h24h 12.3% ($r = .350$). This model shows that more adverse driving events will occur in a 6-week period for: each year younger in age (0.71 events); membership in the SW group (11.15 events), each point higher on the PSQI Score (1.13 more events), and with each percentage of 14-days with <6h/24h sleep (.09 events). To adjust the percentage of 14-days to day units, for each day of sleep <6h24h, this would equate to an additional 0.64 events reported.

Table 4-3 Summary of Multiple Linear Regression Model for 6-week Sum of Adverse Driving Events

Model	*B*	*SE*	*Beta*	*t*	*p*	*95% CI for B*
Model 1						
Age	-.72	.13	-.58	-5.36	**<.001**	[-1.00, -0.45]
Group	-11.81	2.97	-.46	-3.98	**<.001**	[-17.88, -5.75]
PSQI Score	1.20	.34	.33	3.52	**<.001**	[0.50, 1.90]
TST, percent of days <6h/24h	.09	.05	.18	1.70	.10	[-0.02, 0.20]
SE, 14-day Avg.	-.03	.19	-.01	-.14	.89	[-0.40, 0.35]
ESS Score	.06	.40	.02	.16	.87	[-0.75, 0.87]
KSS maximum, 14-day Avg.	-.44	1.02	-.04	-.43	.67	[-2.53, 1.65]
1-Year sum of adverse events	-.08	.07	-.10	-1.14	.26	[-0.23, 0.07]
Continue to drive when sleepy	-.09	.41	-.02	-.22	.83	[-0.92, 0.75]
DBQ Full Scale, average	2.80	3.83	.07	.73	.47	[-5.03, 10.63]
OTMT-A, *z* -score	-.14	1.12	-.01	-.12	.90	[-2.43, 2.16]
Model 8						
Age	-.70	.09	-.57	-7.58	**<.001**	[-0.89, -0.51]
Group	-11.15	2.21	-.43	-5.06	**<.001**	[-15.63, -6.68]
PSQI Score	1.13	.30	.31	3.71	**<.001**	[0.51, 1.74]
TST, percent of days <6h/24h	.089	.04	.17	2.24	**.031**	[0.01, 0.17]

Dependent Variable: 6-week Sum Adverse Driving Events. B = unstandardized regression coefficient, SE = standard error, Beta = standardized regression coefficient, t = independent samples t-test, p = significance (= <.05), CI = confidence interval for unstandardized regression coefficient. TST = Total Sleep Time, PSQI = Pittsburg Sleep Quality Index Scale, SE = Sleep Efficiency, KSS = Karolinska Sleepiness Scale, DBQ = Driving Behaviour Questionnaire, OTMT-A =Oral Trail Making Test A.*

4.4 Discussion

This study examined the correlations and predictive validity of demographic, sleep-related, and driving performance-related indicators on the 6-week sum of self-reported adverse driving events in healthcare workers. Overall, findings supported the hypothesis that a higher 6-week sum of adverse events would be associated with lower overall sleep quantity, sleep quality, higher subjective sleepiness, higher 1-year history sum of adverse driving events, poorer driving behaviour, and poorer cognitive driving ability, and younger age. However, only certain outcome measures within these domains had significant predictive validity. Factors predictive of the 6-week sum of adverse events were limited to four: SW group, younger age, and lower sleep quantity and quality.

The correlational analysis demonstrated that a higher 6-week sum of adverse driving events was significantly associated with demographic factors (e.g., younger age, shiftworkers, working longer shifts); lower sleep quantity and quality (e.g., lower minimum TST, more frequently sleeping <6h/24h, lower sleep efficiency, higher PSQI score); sleepiness (e.g., higher scores on ESS or KSS); and personal factors influencing sleep (e.g., higher scores on rMEQ, WFC-Time, WFC-Strain). Significant associations with driving performance outcomes included a higher 1-year history of adverse driving events, higher reported frequency of continuing to drive after noticing signs of sleepiness, higher self-reported risky driving behaviours via the DBQ, and lower performance on a measure of cognitive driving ability (OTMT-A).

Previous research shows an association between adverse driving events occurring on a specific drive with higher ratings of subjective sleepiness (e.g., KSS) immediately before (Anderson et al., 2018) or while driving (Knott et al., 2020). The present findings further demonstrate that longer duration averages (e.g., 14-day) for maximum or overall subjective sleepiness while driving (e.g., KSS) also show a significant association and moderate to good relationship with the sum of adverse events over a 6-week period. Similarly, we extend findings for the relationship between sleep quantity and adverse driving events, finding significant associations for measures of sleep quantity over a 14-day period (e.g., minimum recorded TST or percent of sleep logs with <6h/24h). Finally, prior literature has scant evidence pertaining to associations between adverse driving events and scores on commonly used standardized questionnaires on sleep quality (e.g., PSQI) or daytime sleepiness questionnaires (e.g., ESS). Findings in this study show significant associations for both PSQI and ESS questionnaires, which suggest future steps for research and clinical screening to identify at-risk SW.

Next, a multiple regression model showed that younger age, shiftwork employment, poor sleep quality (via higher PSQI scores), and more frequent insufficient sleep (<6h/24h) significantly predicted a higher 6-week sum of adverse driving events. This model showed a good fit to the data, explaining 77.7% of the variance in the 6-week sum of adverse events. As anticipated, participants working 12h rotating day/night shifts (SW Group) was a significant predictor of the 6-week sum of adverse driving events. This finding builds on the significant between-groups differences in adverse driving events summarized in Chapter 3 (pages 88-107). This is also consistent with the findings of a systematic review indicating that overnight shiftwork likely predicts adverse driving outcomes in driving simulators or closed road course conditions (Knott et al., 2020). Notably, younger age was identified as a significant predictor of a higher 6-week sum of adverse driving events. This finding builds on existing research that suggests younger drivers may be more vulnerable to the effects of insufficient sleep and demonstrate poorer driving performance than older drivers with equivalent insufficient sleep (Cai et al., 2021; Soleimanloo et al., 2017). However, prior research on sleep and driving performance in shiftworkers has had few younger workers and none under the age of 24 (Knott et al., 2020), thus limiting the ability to obtain such findings related to age. The significant predictive validity of younger age on adverse driving events in this study underscores the importance of including younger workers in future research.

Poor sleep quality (e.g., higher PSQI scores) and more frequent episodes of insufficient sleep quantity (<6h/24h), were the final two factors predictive of the 6-week sum of adverse driving events. These findings are notable for several reasons. First, certain healthcare occupations (e.g., nursing) have a high prevalence of poor sleep quality, affecting 65.4% of those working rotating shifts, with younger workers more likely to be categorized as having poor sleep quality (Zeng et al., 2020). Second, findings in Chapter 3 (pages 104-109) showed that the SW group had significantly higher PSQI scores (p = .004), more SW categorized as having poor sleep quality (SW = 95.7% versus DW = 69.6%, p = .034), and SW had significantly more sleep logs with <6h/24h sleep (SW = 39.2%, versus DW = 24.1%, p <.001). While insufficient sleep has been shown to predict adverse driving outcomes on single drives in shift workers, to date, a self-report measure such as the PSQI has not been shown to predict future occurrences of adverse driving events. The PSQI is a freely available, self-report questionnaire that examines sleep quality in the past month, that may be used to screen for sleep quality. However, it is notable that the scoring for this tool may be cumbersome and that this may limit its uptake for individual lay users of the tool outside of clinical or research settings.

4.4.1 Limitations

Data collection occurred during the COVID-19 pandemic, in the context of significant staffing shortages in healthcare settings within which participants were employed, in addition to the impacts of the pandemic restrictions on the general population (Hassan, 2022; Porter, 2022). Thus, it is possible the effects in this study may be larger than in other studies, or, limited in generalizability beyond the Canadian healthcare setting. The data used for this dependent variable is based on 14-days of driving logs (e.g., 28 logs), plus a 1-month follow up survey. The effects of recall bias may result in participants under-reporting the true total number of adverse events in the 1-month follow up period. Given the relatively short period to track some adverse events (e.g., near miss, crash), longer periods of data collection may be required, and a larger sample size would improve the power of the statistical analysis to detect significant correlations and predictor variables. Multiple comparisons were computed on certain dependent variables, increasing the risk of a Type I error. To address this, Bonferroni adjusted alpha levels were used (Portney & Watkins, 2009b).

4.4.2 Strengths

This work has several strengths. First, this study focuses on historically under-represented participants across a broad range of entry-level healthcare occupations (e.g., nurses, paramedics), with majority female participants. Through including both full-time employed workers (87%) as well as those working equivalent to full time across multiple or flexible scheduling (13%), this study included younger workers (R=20-58 years) and with a wide range of work experience (*R* = 1-34 years). This design intended to increase the participant representation to more closely resemble those employed in the healthcare sector. Indeed, the results of this study show that younger workers, previously systematically excluded from this type of research, were shown to more likely to experience adverse driving experiences than older drivers.

Further, this study builds on data for 24h sleep or subjective sleepiness and adverse driving events by demonstrating significant correlations with independent variables focusing on longer-term patterns. Specifically, sleep quantity over the past 14-days and sleep quality over the past month (e.g., PSQI) both significantly contributed to predicting the sum of adverse driving events occurring over a 6-week period.

4.4.3 Implications

The results of this study have important implications for future research, healthcare worker curriculum, workplace policy and clinical practice. The predictor with the greatest magnitude and significance on the sum of adverse driving events occurring within a 6-week period was identified as the age of the healthcare worker. However, research on sleep, sleepiness and driving performance in shiftworkers has historically excluded younger workers, particularly those under the age of 24 (Knott et al., 2020). These study results, in the context of other work that indicates younger drivers have more difficulty recovering from SW fatigue (Winwood et al., 2006) perform more poorly following sleep deprivation than older drivers (Cai et al., 2021), highlight the critical need to focus future research efforts on the driving performance of younger shiftworkers. Further, future research could further examine cut points to validly determine who is at risk for adverse driving events. Further, these findings indicate a need to integrate education on sleep into healthcare worker educational curriculum, new employee orientation and health & safety training, to increase awareness particularly focusing on the youngest shiftworkers. Finally, clinicians working with shiftworkers via occupational health, sleep medicine, or driving rehabilitation may consider shift worker age, sleep quality using the PSQI, and frequency of insufficient sleep, to educate shiftworkers on potential risks for driving associated with these factors.

4.5 Conclusions

This study showed that younger age, being employed in shift work, reporting poorer sleep quality via the PSQI, and more frequently experiencing insufficient sleep (<6h/24h) significantly predicted a higher total sum of adverse driving events in a 6-week period. These findings have important implications on identifying potential at-risk healthcare workers (e.g., new graduates employed in shiftwork), and potential screening methods, via screening for sleep quality in the past month via the PSQI and the frequency of days insufficient sleep (e.g., <6h/24h sleep). Such measures may be integrated into the formal curriculum for healthcare providers, as well as new employee workplace orientation. Proactively targeting the youngest shiftworkers may aid sleep quality and quantity, and awareness of the impacts of insufficient sleep on driving performance. These results further highlight the critical need to focus future research efforts on young shiftworkers as a particularly at-risk group of drivers for longer-term adverse driving outcomes.

4.7 References

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5 Discussion

The purpose of this dissertation was to examine sleep, sleepiness, and driving performance in healthcare shiftworkers (HCSW) using a mixed-methods approach. The first aim (chapter 2) was to quantify and describe HCSWs' sleep-related driving experiences and advance the understanding of occupational adaptations used by HCSWs to meet driving demands. The second aim (chapter 3) was to quantify between-groups differences in sleep, sleepiness, and driving performance outcomes in healthcare workers who work 12-hour rotating day/night shifts compared with those who work regular day shifts. Existing research suggests that SW may experience reduced sleep quantity and quality, elevated sleepiness, and aspects of impaired driving performance compared to DW. Thus, we hypothesized that HCSW would demonstrate lower sleep quality and quantity, elevated levels of sleepiness, and poorer driving performance across multiple domains (e.g., driving history, habits, behaviours, abilities, and events). The third aim (chapter 4) was to identify indicators (e.g., driver demographics, sleep, sleepiness, or driving performance outcomes) that may predict the total number of adverse driving events reported by healthcare workers in a 6-week period. Existing research suggests increased risks for sleep-related MVC for drivers who are younger, shiftworkers, who report poor sleep and/or elevated sleepiness, and who report a history of adverse or sleep-related driving events. Thus, we hypothesized that these demographics, sleep- and/or driving performance factors may predict the 6-week sum of adverse driving events reported in healthcare workers. This chapter summarizes the key findings of each of these three objectives, provides an overview of contributions to the literature, limitations and strengths, and implications of the findings on future research, healthcare worker education, policy, and clinical care.

5.1 Main Findings

5.1.1 Objective One

The first objective was addressed in chapter 2 (pages 25-62). This study aimed to quantify and describe HCSWs' sleep-related driving experiences, and advance understanding of HCSWs' sleep-related driving experiences and contextual factors influencing occupational adaptations. This study employed an explanatory sequential mixed-methods quantitative dominant design, comprised of an online survey of 25 HCSW (Phase One, quantitative), and follow-up one-to-one interviews with 13 HCSW who reported sleep-related driving events in the past year (Phase Two, qualitative). Twenty respondents completed the online survey, with participants being majority female (80%), employed as nurses (75%) or paramedics (25%), and across a wide range of ages (*R* = 21-58 years) and work experience (*R* = 1-36 years). Survey findings indicate that HCSW are an at-risk group of drivers: 90% reported severe sleepiness while driving in the past year, with 41% nodding off, and 12% falling asleep. Furthermore, of those with sleep-related driving history, 94% reported adverse driving events in the past year, with a median number of 15 events (*R* =1-79). Types of reported adverse driving events suggested difficulties with alertness (e.g., startle awake in the same lane, memory gaps, or missing lights/turns), and/or lane maintenance (e.g., hitting the rumble strips at the edge of the road, crossing the centre line, wandering lanes). The occurrence of insufficient sleep increased in frequency and severity throughout the workweek, with 40% of HCSW obtaining severely insufficient sleep (i.e., <5h/24h) at levels proposed as impaired driving for the vast majority of drivers (Dawson et al., 2021). Further, participants with a 1-year sleep-related driving history showed trends toward shorter and more variable sleep quantity.

Interview data suggest that despite HCSW using multi-layered efforts to mitigate sleep-related driving events (e.g., proactively avoid, plan ahead, prepare on-shift, and increase alertness and push through), sleep-related driving events were described as routine and predictable. Participants described driving with altered situational awareness and cognition, as if on autopilot; and relied on adaptations gained via experiential and informal learning in the context of limited formal training or resources. Further, participants indicate multiple systemic barriers that may disproportionately affect younger or less experienced HCSWs. Such barriers may exacerbate risk for adverse driving events or road traffic injuries for younger workers, given that younger drivers are more prone to adverse driving outcomes associated with insufficient sleep (Cai et al., 2021).

5.1.2 Objective Two

The second objective of this thesis was detailed in chapter 3 (pages 63-120). This study aimed to determine what differences exist between groups of healthcare workers who work rotating day/night shifts (SW) and those who work regular day shifts (DW) in sleep quantity, quality, self-reported sleepiness, and driving performance outcomes (e.g., driving history, habits, behaviours, abilities, and events). Participants were comprised of 23 SW and 24 DW who were majority female (72%), and ranged from 21-58 years of age, and 1-36 years of work experience. Overall, SW demonstrated a significantly lower average sleep quantity, and a significantly higher percentage of days with severely insufficient sleep (i.e., <5h/24h, SW 22.5% vs DW 7.5%). SW reported significantly poorer sleep quality in the past month, with 95.7% of SW meeting the criteria for poor sleep quality. Overall, SW reported higher subjective sleepiness while driving and a significantly higher percentage of SW reported episodes of severe sleepiness within a 14-day period (SW 52% vs DW 9%).

Over multiple time points (e.g., 1-year driving history, 14-day prospective data collection and 1-month follow-up survey), SW consistently reported more frequent occurrences of severe sleepiness or nodding off while driving and adverse driving events (e.g., sleep-related, inattention, hazardous). No differences were identified for falling asleep, adverse driving events classified as violations, driving record citations, self- or proxy-rated driving behaviours, or driving abilities assessed. Results were mixed for driving habits, with SW initially indicating a higher median frequency of continuing to drive after noticing sleepiness, yet this was no longer significant at the 1-month follow-up.

5.1.3 Objective Three

The third objective of this thesis was addressed in chapter 4 (pages 121-140). This study aimed to determine correlations and predictive validity of demographic, sleep-related, and driving-related indicators on the 6-week sum of adverse driving events reported by healthcare workers. Participants included 23 SW and 22 DW who completed all the study procedures outlined in chapter 3. A higher 6-week sum of adverse driving events was significantly correlated with shiftwork employment, younger age, lower sleep quality and quantity, higher sleepiness, higher scores on measures for chronotype and work-life conflict, a higher 1-year history of adverse driving events, more frequent driving after noticing sleepiness or risky driving behaviours, or poorer performance on cognitive driving ability measured via the OTMT-A. A multiple regression model identified four factors that significantly predicted the 6-week sum of adverse driving events, explaining 77.7% of the variance. The four factors predicting a higher 6-week sum of adverse driving events included shiftwork employment, younger age, poorer self-rated sleep quality in the past month (i.e., a higher PSQI score), and more frequent occurrence of insufficient sleep (i.e., <6h/24h) within a 14-day period. These findings suggest the need for increased focus on research, education, targeted towards younger HCSW, and screening and interventions for those with poor sleep quality and quantity.

5.2 Contributions to the Literature

This dissertation builds on existing research examining shiftworker driving performance outcomes by increasing the representation of historically under-represented groups, using a broad conceptualization of driving performance, and collecting data online and remotely using multiple methods to meet the demands of the COVID-19 pandemic. Outcome measures examined multiple areas of driving performance (e.g., history, habits, behaviours, abilities, events), and included multiple modes of data collection (e.g., self- and proxy-report, objective driving records, objective sleep data and cognitive screening) over several time points. Using these approaches, the findings of this dissertation advance the understanding of healthcare shiftworkers sleep, sleepiness, and driving performance and contextual factors influencing occupational adaptations; quantifies between-groups differences between SW and DW sleep- and driving-performance outcomes; and identifies demographic and sleep-related indicators predictive of adverse driving events.

This dissertation addressed gaps in participant demographics by focusing on groups historically under-represented in research sleep and driving performance in shiftworkers. Prior research in SW driving performance included few younger workers, none under 24 (Knott et al, 2020), and required participants to be employed in full-time positions that are less common amongst younger or low-seniority workers (Williams, 2008). Healthcare workers included in this dissertation research were employed in multiple disciplines, were majority female (72% to 80%), and represented a broad spectrum of age (21 to 58 years) and work experience (1 to 36 years). Importantly, this study included participants with 1 year or more of experience in either full-time positions (85% to 91%) or full-time-equivalent hours between multiple positions (9% to 15%). Including a broad demographic of participants employed in healthcare occupations enhanced qualitative data collection via the diverse lived experiences and perspectives and reduced the impacts of selection bias and survivor cohort in existing quantitative research. As a result, findings from this dissertation show that younger HCSW age predicted a higher sum of adverse driving events, and, that younger HCSW faced additional systemic barriers in adapting to the demands of shiftwork and driving.

Findings on sleep indicate that mild to severe levels of insufficient sleep, poor sleep quality, and elevated levels of subjective sleepiness are pervasive amongst HCSW and occur with greater frequency and intensity (versus DW). More mild insufficient sleep (<6h/24h) that may negatively impact cognitive functions in key areas required for driving (Banks et al., 2017; Barco et al., 2012) was reported by 65% of HCSW on their final shift of the workweek (chapter 2) and observed in 39.2% of SW sleep logs (chapter 3). The frequency of sleep below this level significantly predicted the 6-week sum of adverse driving events (chapter 4). Critically, severely insufficient sleep (e.g., <5h/24h), below which the vast majority of drivers may be deemed to be impaired (e.g., equivalent to alcohol-impaired driving) (Dawson et al., 2021) was reported by 40% of HCSW at least once weekly (chapter 2) and shown in 22.5% of all SW sleep logs (chapter 3). Moreover, 95.7% of HCSW met the criteria for poor sleep quality in the past month, and HCSW reported overall higher ratings of subjective sleepiness while driving for any purpose or shift type, indicating that these differences persist beyond post-shift driving, which is the primary focus of current driving research.

HCSW reported a significantly higher frequency of severe sleepiness or nodding off while driving, and adverse driving events (e.g., sleep-related, inattention, hazardous) over multiple time points (e.g., 1-year driving history, 14-day prospective data collection and 1-month follow-up survey). Demographic and sleep-related indicators significantly predict the sum of adverse driving events in a 6-week period, including shiftwork employment, younger age, longer-term patterns of poor sleep quality and the frequency of insufficient sleep.

HCSWs are an essential workforce required to provide 24h care in hospital and pre-hospital emergency settings, and at the population level, represent a significant number of shiftworkers and road users. Thus, the findings of this dissertation have important implications in multiple domains, including for future research, healthcare provider education through formal curriculum and workplace training, institutional policies, and clinical practice.

5.3 Implications

5.3.1 Future Research

Findings from this dissertation can inform future research on the impact of shift work on sleep, sleepiness and driving performance outcomes, and inform the development of screening and prevention-oriented interventions. Current research and strategic priorities within Canadian healthcare professional organizations (e.g., nursing and paramedicine) include examining the impact of shift-work schedules and shift length on employee health, sleep and fatigue; identifying factors that influence workplace fatigue; and developing policies that support healthy work environments (Canadian Nurses Association, 2010; Tavares et al., 2021). These research priorities align with the findings and implications of this dissertation research.

Findings in chapter 3 demonstrate that insufficient sleep quantity and poor sleep quality in HCSW working 12h rotating shifts is pervasive, and that the frequency and severity of insufficient sleep and poor sleep quality are factors predictive of future adverse driving events. Future research may examine whether shorter duration (e.g., 10h) shifts may reduce the negative impacts on sleep quality, sleep quantity, and the frequency and severity of insufficient sleep obtained by HCSW. While 12h shifts are currently extensively used in Canadian healthcare settings professional to organizations recommend examining whether shorter duration shifts may be of benefit (Canadian Nurses Association, 2010).

In chapter 2, HCSWs described their experiences of driving with sleepiness as including altered awareness and cognition a decreased ability to recognize and respond appropriately to salient cues in the driving environment (e.g., driving through a red light). Such descriptions are congruent with performance impairments arising from cognitive deficits related to insufficient sleep (e.g., deficits in awareness, alternating attention, information processing) in naturalistic settings combined with self-report driving logs (e.g., video recording both the roadway and the drivers' visual gaze, kinematic data of vehicle movement and speed). Using vehicle instrumentation could enhance data collection and analysis by trained driving evaluators. Pairing the analysis of self-reported driving events with the analysis of vehicle instrumentation would enable researchers to examine correlations between self-report and evaluator-assessed instances of sleep-related or adverse driving events. Further, trained evaluators could examine driving performance for more complex constructs such as visual scanning of the driving environment (e.g., eye, head, and neck movements required to observe objects, hazards, and traffic flow) and adjustment to stimuli (e.g., appropriately responding to observed cues) (Alvarez et al., 2018). These types of outcomes are used in on-road and simulator-based driving assessment and intervention studies in other clinical populations but are not currently reported in either naturalistic or simulator-based studies for insufficient sleep. Such approaches could inform potential avenues for assessment and/or intervention.

Findings in chapter 4 showed that shiftwork employment, younger age, poorer self-rated sleep quality in the past month, and higher frequency of insufficient sleep (<6h/24h) significantly predict future adverse driving events, may aid in identifying higher-risk SW. These results highlight the critical need to focus future research efforts on younger shiftworkers as a particularly at-risk group of drivers for longer-term adverse driving outcomes. Since the findings in this dissertation are based on a healthy population of HCSWs, future research may expand to include those with diagnosed medical conditions that may impact sleepiness or driving (e.g., sleep apnea, insomnia), given that drivers with medical conditions may be more vulnerable to the effects of insufficient sleep on driving performance (Czeisler et al., 2016). Building on this research to further examine sleep, sleepiness, and driving performance in HCSW who are younger or who have medical conditions may identify additional factors that predictor adverse driving outcomes.

Together, the above examples of future research (e.g., experiences of HCSW without sleep-related driving experiences, shorter shift length, additional driving outcomes within naturalistic settings, and younger or medically vulnerable HCSW) would aid in developing and tailoring screening and prevention-oriented interventions. HCSWs' lived experiences of sleep-related driving events, and contextual factors informing occupational possibilities and adaptations may inform the feasibility of future interventions.

5.3.2 Education and Training

The findings in this dissertation suggest significant implications for formal education and workplace training. Interview data in (chapter 2) indicated HCSW lacked basic formal education on sleep and sleepiness, recognizing the effects of insufficient sleep, and evidence-based self-management strategies. Such foundational knowledge is required to understand risks and implement changes for self-management of sleep and sleepiness (Khader et al., 2021), and recognize sleep-related impacts on driving performance in order to proactively engage in occupational adaptations (e.g., roadside or in-vehicle countermeasures). Our findings show that younger HCSW age was one of four factors predicting the number of adverse driving events experienced and that younger HCSW faced additional systemic barriers to obtaining sufficient sleep and learning and occupational adaptations to manage driving in this context. Together, this suggests that targeting students and new graduates from healthcare provider programs may be of particular benefit for educational initiatives. Shiftworker education is also recommended by healthcare professional organizations and the National Highway Traffic Safety Administration (Canadian Nurses Association, 2010; Goodwin et al., 2013). Agencies have developed materials for education of shiftworkers and general public (Goodwin et al., 2013) and via an online workshop for psychology graduate students' clinical skill development (Meaklim, Rehm, et al., 2023). This online workshop improved participant sleep outcomes (82%) (Meaklim, Rehm, et al., 2023), showed high rates of adoption by university programs (70%), and strong student enrollment (81%) (Meaklim, Meltzer, et al., 2023). Therefore, future programs for other healthcare professional programs may consider building on this approach and examining outcomes in other healthcare providers. While younger HCSW may be the primary target for education, extending educational opportunities to experienced HCSW (e.g., preceptors, supervisors, and management) may enable a workplace culture supporting healthy sleep and overcome barriers to implementing workplace interventions to address insufficient sleep and its downstream effects (Canadian Nurses Association, 2010; Geiger-Brown et al., 2016).

5.3.3 Policy

The findings of this dissertation have several important implications on policy, given the integral nature of policy on multiple aspects relevant to healthcare worker education, employment, and transportation. These include setting requirements for formal education and professionalism (e.g., curriculum, workplace health and safety training), institutional human resources (e.g., shift schedules, break access and physical space, access to alternative transportation), and defining driver fitness in the context of insufficient sleep. Interventions addressing the impact of insufficient sleep on driving performance in HCSW may target one or more levels, ranging from individual to population-level public health approaches (Hale et al., 2020), all of which may be significantly influenced by policy. These range from the individual level (e.g., knowledge of sleep hygiene, screening for risk factors); interpersonal level (e.g., family, friends, co-workers); employment and healthcare level (e.g., workplace policy, built environment), and/or the public policy level (e.g., public health campaigns, legislation defining impaired driving by fatigue)(Hale et al., 2020). Evidence-informed policies would serve to enhance foundational knowledge required to reframe sleep as a necessity, increase occupational possibilities and access to evidence-informed occupational adaptations to mitigate the impact of insufficient sleep on driving performance. Given the multiple layers and foci of interventions that may be required, engaging a multi-stakeholder partnership approach may be required to successfully navigate policy changes impacting HCSW.

Indeed, findings in this dissertation show significantly higher rates of mild and severely insufficient sleep and poor sleep quality in HCSW (versus DW), and that poor sleep quality and more frequent occurrences of insufficient sleep are factors predictive of future adverse driving events. Policy ensuring formal education on sleep would enable knowledge exchange and uptake to not only HCSW but also those in leadership and policy-setting roles to acknowledge the essential nature of sleep and the adverse impacts of insufficient sleep. Such knowledge would support reframing sleep from optional to a neurobiological necessity, underscoring the multiple negative downstream effects associated with insufficient sleep (e.g., driving performance outcomes; health and safety of HCSW and patients albeit outside the scope of this dissertation). Understanding how contextual factors outside of the control of the individual (i.e., occupational deprivation of sleep arising from shiftwork) (Leive & Morrison, 2020) result in insufficient sleep would support the recognition of SW’s occupational rights to engage in required occupations freely and without coercion or risk to safety or employment to support their own health and wellbeing. Language reframing sleep as an occupational right for HCSW would be consistent with identifying insufficient sleep as a hazard in the workplace and on the road, and necessary to implement policy changes in workplace settings (Dawson et al., 2021). Currently, in Canada insufficient sleep is not defined as it pertains to determining driver fitness (Canadian Council of Motor Transport Administrators, 2020), nor is insufficient sleep addressed in relevant occupational health or workplace safety legislation. Thus, institutions lack specific guidance on defining insufficient sleep, hampering the impetus to implement policy-level interventions to mitigate the downstream effects of insufficient sleep (Dawson et al., 2021).

Policy-level interventions may include supports to enable occupational adaptations in macro-level strategic, and strategic driving behaviours (e.g., access to predictable breaks, support to rest on breaks to manage fatigue, predictable scheduling, alternate shift length and/or patterns to suit individual tolerance, provision or facilitation alternate transportation). Napping or resting during break times (i.e., intra-shift napping) was highlighted by HCSW as a key component to self-managing sleep and sleepiness, and mitigating sleep-related driving events. Evidence supports the use of intra-shift napping to reduce insufficient sleep, sleepiness, and improve performance (Li et al., 2019; Sun et al., 2019), and nursing associations formally recommend this in best practice policies (Canadian Nurses Association, 2010). However, barriers and stigma exist, and uptake of intra-shift napping is limited (Geiger-Brown et al., 2016). Given that the cutoffs for insufficient sleep are of total sleep quantity within a 24h period, (i.e., main sleep and nap period summed), integrating brief naps during existing break times may make a meaningful contribution to total sleep time, and reduce the frequency of insufficient sleep. Further, increasing awareness of and access to alternative transportation options may reduce driving demands during times when HCSW experiencing insufficient sleep. Increasing access to these resources, and/or offering pre-paid taxi/e ride-share credits for HCSW to use at times when they have had insufficient sleep (e.g., after a call-in shift with insufficient notice to sleep beforehand) or self-identify that they are experiencing significant sleepiness and do not feel safe driving home. Pilot studies examining alternative transport ideas with good employee uptake and reduced occurrence of sleep-related driving events, reduced barriers to access, with only modest costs (White et al., 2021).

5.3.4 Clinical Practice

Results from these studies can inform aspects of clinical practice across multiple healthcare practice areas, including occupational medicine, sleep medicine, occupational health and safety, and driver rehabilitation. Healthcare providers working with HCSW may consider screening for the four factors predictive of a higher 6-week sum of adverse driving events (e.g., shiftwork employment, younger age, frequency of insufficient sleep quantity (<6h/24h), poor sleep quality via the Pittsburg Sleep Quality Index). Together with the systemic barriers to occupational adaptations, a focus on younger shiftworkers is warranted and clinically relevant. Providing education to increase awareness of the impacts of insufficient sleep on driving performance, and consider individually targeted interventions to address sleep, sleepiness, and driving performance is warranted.

5.3.5 Limitations

Data collection for the two studies conducted for this dissertation occurred during the COVID-19 pandemic between October 2020 and February 2022. In this timeframe, the target population of healthcare workers faced additional pressures that may impact constructs of interest such as sleep and sleepiness. Specifically, staffing shortages within Ontario Canada were well documented in the media (Hassan, 2022; Porter, 2022), and may have exacerbated work demands (e.g., fewer breaks or more call-in shifts to cover shortages) or work-life conflict (e.g., school closures). While these pressures were identified across the Canadian healthcare system, these may not be representative of pressures on healthcare workers in other jurisdictions or time points.

Participant recruitment for both studies relied on convenience sampling, and thus it is possible that those with more significant difficulties with sleep, sleepiness, or driving performance may have been drawn to participate. Similarly, the transferability of the qualitative findings should be interpreted within the context of the participants, setting, and recruitment strategy. Finally, this study was conducted entirely online or via remote data collection to meet the public health precautions required during the pandemic. Therefore, driving skills were unable to be directly observed, and driving abilities were not assessed using traditional in-person clinical assessments. Instead, self-reported driving events were captured via twice-daily driving logs validated in prior research, and a telephone-based screening of driving abilities was conducted using tools validated for oral telephone administration. Multiple comparisons were computed on certain dependent variables, increasing the risk of a Type I error. To address this, Bonferroni adjusted alpha levels were used (Portney & Watkins, 2009).

5.3.6 Strengths

This dissertation employed both mixed-methods and quantitative approaches to examining sleep, sleepiness, and driving performance in HCSW. This multiple methods approach enabled the complementary use of quantitative and qualitative data to advance a multifaceted understanding of the research objectives (Creswell, 2014; Creswell et al., 2011). Using online and remote data collection methods during the COVID-19 pandemic allowed participant recruitment to expand across a broad geographic region of Southwestern Ontario, drawing from rural to mid-size urban centers within a 3-hour radius of London Ontario. This large area of participant recruitment is far beyond the typical recruitment area possible for an in-person study conducted on campus at Western University requiring participants to travel to campus. Thus, participants could complete the study procedures at a time and location of their choosing, reducing their time burden. Further, participants documented their experiences in a naturalistic setting representative of their own work schedule and driving demands (e.g., driving route, environment, traffic conditions, timing, and drive duration). Finally, the healthcare worker target population, inclusion criteria, and recruitment strategy were developed to build on existing research examining sleep and driving performance in shiftworkers. Specifically, this dissertation addresses historically under-represented participant groups, including healthcare workers, women, younger workers, and those not in full-time permanent positions.

5.4 Conclusions

This dissertation examined sleep, sleepiness, and driving performance in healthcare shiftworkers who work rotating shifts using a mixed-methods approach. Through three aims, this dissertation: (1) quantified and described HCSW's sleep-related and adverse driving experiences and advanced understanding of sleep-related driving experiences and occupational adaptations; (2) quantified differences between HCSW and dayworkers (DW) in sleep, sleepiness, and driving performance outcomes; and (3) identified demographic and sleep-related indicators that significantly predict sum of adverse driving events reported in a 6-week period.

The primary findings of this dissertation show that insufficient sleep quantity and poor sleep quality is pervasive in HCSW via both subjective and objective measures. Critically, the occurrence of severely insufficient sleep equivalent to alcohol impairment in the vast majority of drivers was in 22.5% of HCSW sleep logs. Further, 95.7% of HCSW met criteria for poor sleep quality in the past month. Driving performance outcomes show that HCSW demonstrate significantly higher levels of subjective sleepiness while driving, along with higher occurrence of sleep-related and adverse driving events in the past 1-year, during a 14-day prospective trial; and at a 1-month follow-up period. Factors predictive of a higher 6-week sum of adverse driving events include shiftwork employment, younger age, higher score on the Pittsburg Sleep Quality Index indicating poor sleep quality in the past month, and more frequent occurrences of insufficient sleep (<6h/24h). This dissertation concludes that HCSWs are an at-risk group of drivers, secondary to poor sleep quantity, quality, and increased rates of sleep-related and adverse driving events, with 90% to 91.3% reporting severe sleepiness and 94-95% reporting any adverse driving event in the past year. Furthermore, HCSW indicate using multiple layers of recurring occupational adaptations to reduce the occurrence of sleep-related or adverse driving events. Despite such efforts, however HCSW continue to describe these sleep-related and adverse driving events as routine and predictable outcomes following shiftwork. The findings that younger age is a significant predictor of adverse driving outcomes, paired with the systemic barriers of limited training, resources, and unpredictable scheduling, suggest a disproportionate burden on younger HCSW. This research has implications for future research, education and training for healthcare workers, and in policy changes, and clinical practice.

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Appendices

Appendix A - Ethics Approval for Study 1

Date: 1 October 2020

To: Dr. Liliana Alvarez

Project ID: 115781

Study Title: i-SHIFT: Exploring Driving History, Habits and Experiences in Healthcare Shift Workers

Short Title: i-SHIFT Study: Exploring Driving Experiences

Application Type: REB Initial Application

Review Type: Delegated

Full Board Reporting Date: 20/Oct/2020

Date Approval Issued: 01/Oct/2020 11:38

REB Approval Expiry Date: 01/Oct/2021

Dear Dr. Liliana Alvarez

The Western University Health Sciences Research Ethics Board (HSREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. HSREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
i-SHIFT Study.Interview Guide.03Apr2020	Interview Guide	03/Apr/2020	1
i-SHIFT Study.Online Questionnaires.20July2020	Online Survey	20/Jul/2020	2
i-SHIFT Study.Interview Guide.18Aug2020	Interview Guide	18/Aug/2020	2
i-SHIFT.Study.RecruitmentPoster_23July2020	Recruitment Materials	23/Jul/2020	2
i-SHIFT.Study.WebsiteRecruitment.Ad_23July2020	Recruitment Materials	23/Jul/2020	2
i-SHIFT Study_Verbal Consent to Audio Record_23July2020	Verbal Consent/Assent	23/Jul/2020	2
i-SHIFT Study_Letter of Information_Phase2_Interview_20July2020	Implied Consent/Assent	20/Jul/2020	2
i-SHIFT Study.Email Script Recruitment.22Sept2020	Recruitment Materials	22/Sep/2020	3
i-SHIFT Study.Research Protocol.25Sept2020	Protocol	25/Sep/2020	3
i-SHIFT Study_Letter of Information_Phase 1 Survey_22Sept2020	Implied Consent/Assent	22/Sep/2020	3

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
2.6 - technology assessment.iSHIFT.28July2020	Other Materials	28/Jul/2020	1
Mental Health Resources List_23July2020	Other Materials	23/Jul/2020	2
i-SHIFT Study.Email Script_Eligible Survey Participant Code.22Sept2020	Tracked Changes Document	22/Sep/2020	1
i-SHIFT Study.Email Script_Eligible Interview.22Sept2020	Tracked Changes Document	22/Sep/2020	1

i-SHIFT Study.Email Script_Affirmative Consent and Link to Eligibility Screen.22Sept2020	Tracked Changes Document	22/Sep/2020	1

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Katelyn Harris, Research Ethics Officer on behalf of Dr. Joseph Gilbert, HSREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B - Phase Two Semi-Structured Interview Guide

Topic Section	Questions and Prompts
Adverse Events: Experiences & Perceptions	1. In your survey, you report your experiences (e.g., severe sleepiness, nod off, fall asleep, near miss or crash). Please describe one of these experiences, with as much detail as possible, including the day leading up to the event. • Was there anything in particular that contributed to this event? • Did you recognize you felt sleepy before this happened? • What was your motivation to continue driving on this day? • Has this experience influenced how you manage driving now? How so? • Do you have another experience that you would like to share? 2. When you are feeling very sleepy when driving, how do you cope? How did you come to know this strategy? • Do you have a range of strategies to manage sleepiness while driving that you feel work for you? Can you please describe them? • How helpful do you find them? How confident are you that they will work? • What might influence your choice of strategy on a particular day?
Managing Sleep & Sleepiness	3. How do you manage your sleep during shiftwork, and on time off? Can you describe your typical routine, and any strategies you use? • Has your approach to sleep changed over time? How so? • Do you have any concerns with your quality or quantity of sleep? 4. What sorts of discussions, if any, do you have with your coworkers about driving? • Do they see sleepy driving as a problem, or share their experiences? • Has hearing about your co-workers' experiences changed how you manage sleep and driving? How so?
Occupational Adaptation & Possibilities	5. Since you began shiftwork, do you feel that your driving habits have changed over time? How so? What about your ability to overcome sleepiness? Coping strategies? Thoughts about sleepy driving? Confidence around driving? 6. Do you know what strategies other people use to cope with sleepiness while driving? • Have you tried any of those strategies? Why or why not? • If not, why would that strategy not be possible for you?

7. Are you aware of any resources or programs through your workplace that you feel encourage certain approaches to managing driving and sleep around shiftwork?
   - What are they? How do you feel they influence driving?

8. Does your employer provide access to some solutions to manage sleep and driving, such as programs for transportation, sleep rooms, employee training/education, or other resources?
   - Do you actually have the ability to use those resources? If not, what are the barriers?

9. Would you say that there is a certain culture at your workplace around managing sleep, fatigue, and driving? Does this differ within management, supervisors, or colleagues? How so?

10. Has your experience regarding managing sleep, sleepiness, and driving changed during the COVID-19 pandemic? If so, how?

11. Is there anything else that you would like to share with me?

Appendix C Ethics Approval for Study 2

Date: 3 May 2021

To: Dr. Liliana Alvarez

Project ID: 116473

Study Title: i-SHIFT Study 2: Exploring Sleep, Sleepiness, and Driving Performance Healthcare Workers

Application Type: HSREB Initial Application

Review Type: Delegated

Full Board Reporting Date: 18/May/2021

Date Approval Issued: 03/May/2021 16:59

REB Approval Expiry Date: 03/May/2022

Dear Dr. Liliana Alvarez

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study**.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
i-SHIFT.2.Handout.SDMT_Form_28Aug2020	Other Data Collection Instruments	28/Aug/2020	1
i-SHIFT2.Telephone Script.OTMT-AB.Instructions_28Aug2020	Other Data Collection Instruments	28/Aug/2020	1
i-SHIFT.2.Survey.Eligibility_Screening.Questions.16Oct2020	Online Survey	16/Oct/2020	1
i-SHIFT.2.Email Script_Post-Phone Call_Link to LOI C.31Jan2021	Email Script	31/Jan/2021	1
i-SHIFT.2.Survey.FTDS_Proxy_Rater_LOI_C_Survey_16Feb2021	Online Survey	16/Feb/2021	2
i-SHIFT.2.Telephone_Script.Recruitment.10Jan2021	Written Consent/Assent	10/Jan/2021	1
i-SHIFT.2.Survey.HealthcareWorker.Contact-Group-Matching-Information.03Mar2021	Online Survey	03/Mar/2021	2
i-SHIFT.2.Survey.DailyLog-Work_Sleep_Driving.22Mar2021	Online Survey	22/Mar/2021	3
i-SHIFT.2.Survey.One_Month_Follow_up.31Mar2021	Online Survey	31/Mar/2021	2
i-SHIFT.2.Survey.IntakeSurvey.31Mar2021	Online Survey	31/Mar/2021	3
i-SHIFT.2.Survey.PaperHandout.DailyLog-Work_Sleep_Driving_22Mar2021	Paper Survey	22/Mar/2021	1
i-SHIFT Study Part 2.Research Protocol.15Apr2021	Protocol	15/Apr/2021	4
i-SHIFT.2.Handout.Sleep Log.Watch Instructions.15Apr2021	Paper Survey	15/Apr/2021	3
i-SHIFT.2.Handout.Equipment Package Instructions.15Apr2021	Paper Survey	15/Apr/2021	3
i-SHIFT.2.Recruitment.Website.Ad_15Apr2021	Recruitment Materials	15/Apr/2021	3
i-SHIFT.2.RecruitmentPoster_15Apr2021	Recruitment Materials	15/Apr/2021	3
i-SHIFT.2.Email Script.GeneralRecruitment.15Apr2021	Email Script	15/Apr/2021	3
i-SHIFT.2.Email Script.Past Participant.Recruitment.15Apr2021	Email Script	15/Apr/2021	3
i-SHIFT.2.Email Script_FTDS_Proxy Rater Invite.15Apr2021	Email Script	15/Apr/2021	4
i-SHIFT.2.Email Script_Interested Participant Response.15Apr2021	Email Script	15/Apr/2021	4

i-SHIFT.2.Email Script_Affirmative Consent_Link to Eligibility Screen_15Apr2021	Email Script	15/Apr/2021	3
i-SHIFT.2.Email Script_Eligible Survey Participant Response.15Apr2021	Email Script	15/Apr/2021	3
i-SHIFT.2.Letter of Information_HealthcareWorker_15Apr2021	Written Consent/Assent	15/Apr/2021	4
i-SHIFT.2.Letter of Information_FTDS Proxy Rater_15April2021	Written Consent/Assent	15/Apr/2021	4

No deviations from, or changes to, the protocol or WREM application should be initiated without prior written approval of an appropriate amendment from Western HSREB , except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Ms. Katelyn Harris , Ethics Officer on behalf of Dr. Joseph Gilbert, HSREB Vice-Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix D - Participant Instructions for Philips Actiwatch

Philips Actiwatch Spectrum User Instruction Version Date: 15/04/2021

1. **Please wear the Actiwatch snugly on your non-dominant wrist**. The Actiwatch is a wrist-worn activity and sleep data recorder. It provides information about general activity, sleep schedule, naps, wake episodes, sleep quality and quantity, and light exposure.

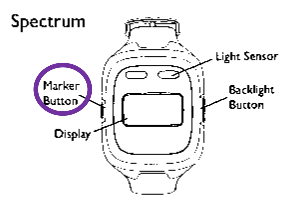
2. **Please fill out daily log (opposite side) in as much detail as possible, beginning the day before your first shift of the week. Most people find it helpful to store this log on a bedside table.** This information is essential for interpreting and scoring your sleep data.

3. **The watch is set to start data collection 24 hours before your workweek begins, and then it will collect sleep and activity data continuously for 14 days.** Please begin wearing the watch 24 hours before you being your first shift of the week (e.g., 7am Sunday morning if your first shift begins 7am Monday morning). **We request that you wear the Actiwatch for the full 14 days.**

4. **The button on the left side of the watch is an Event Marker**. The event marker helps us accurately interpret the sleep data.

Please press and hold this Event Marker button for 3 seconds when:

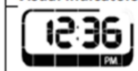
- *Attempting to fall asleep (main sleep & naps)*
- *Waking up from sleep (main sleep & naps)*
- *Any time you must remove the watch*

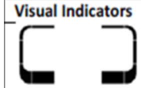


5. **The Actiwatch is water resistant** (up to 1.0m deep for 30 minutes, **but NOT saltwater**). Watches are thoroughly sanitized between users. You may clean it with mild soap and water as needed, and it may be worn in the shower or bath.

6. **Wearing an Actiwatch carries the same level of risk as wearing a regular wristwatch.** If you have skin sensitivity, you may place the watch on top of clothing (e.g., shirtsleeve). Discontinue if skin reddening or inflammation appears. Should a workplace prohibit wearing wristwatches in certain environment, please follow your workplace rules for the Actiwatch as well (e.g., may possibly apply in the presence of oxygen use, radiation or magnetic fields, per the health and safety directions of your workplace). In such instances, the watch may be removed and securely stored until you're able to resume wearing it, and note in the sleep log the time it was removed.

Watch Display Indicators

Visual Indicators	Description
	Shows the time of day
	When you press the backlight button and hold it for 3 seconds, the date is shown as MM-DD.
 (circling clockwise)	The circling black border indicates that data collection has begun.
(A pattern appears on the display and the backlight turns on briefly)	Indicates that you have successfully marked an event by pressing the Marker Button for 3+ seconds.

Visual Indicators	Description
 (flashing)	Indicates that the device is not fastened properly on your wrist. It might be too loose or too tight. Refasten the device to your wrist until the flashing stops.
(Backlight turns on)	Indicates that the backlight button has been pressed. The backlight button automatically turns off after 5 seconds.
	When these symbols appear, the Actiwatch Spectrum's battery is running low. Call study staff if this occurs.
 (or blank screen)	Indicate the data collection is complete or that the device is in sleep mode. Call study staff if this occurs.

If you have any questions or problems with the watch contact [x]. At end of day 14, please arrange to return the watch and this page.

Appendix E - Participant Sleep Log

Participant code: ___________					i-SHIFT Study Sleep Log					Version Date: 22/03/2021		
Date		Main Sleep						Nap(s)		Watch Removal(s)		Notes
Study Day	Date YY/MM/DD	Lay down in bed *press event marker*	Attempt to sleep	Minutes to Fall Asleep	Wake up at	Rise from bed *press event marker*	Disruptions? Start/End Time	Start Time(s) *press event marker*	End Time(s) *press event marker*	Start Time(s) *press event marker*	End Time(s) *press event marker*	
Day 1 *(day off)*		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 2 *(start work)*		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 3		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 4		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 5		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 6		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 7		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 8		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 9		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 10		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 11		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	___:___ AM / PM	
Day 12		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	
Day 13		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	
Day 14		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM	___:___ AM / PM		___:___ AM / PM		___:___ AM / PM	___:___ AM / PM	

Appendix F - Participant Daily Driving Log

i-MOBILE DRIVING RESEARCH LAB

i-SHIFT 2 Study – Daily Log
Version Date: 03/03/2021

Date: ________ Study Day # __________ Participant ID: _________

DAILY DRIVING LOG: Please remember to complete this each morning and night following your drives to / from work, as soon as possible following your drive.

1. When are you completing this survey?
☐ Morning ☐ Evening

2. What is the total amount of sleep you have had in the past 24 hours? *(Please include your main sleep time and any naps.)*
_________hours ________mins

WORK

3. Did you work yet today?
☐ Yes ☐ No ***If no → skip to # 8***

4. What shift did you work?
☐ Day Shift 12h *(e.g., 07:00 - 21:00)*
☐ Afternoon / early evening 12h *(e.g., 14:00-02:00)*
☐ Night Shift 12h *(21:00 - 07:00)*
☐ Regular day hours *(09:00-17:00)*

5. Start Work at: ______ AM / PM

6. Finish work at: ______ AM / PM

7. Work overtime today?
☐ Yes ☐ No

DRIVING EVENTS

Driving in the past 12 hours
When answering the following questions please reflect on the most recent drive you completed (since the last questionnaire).

8. Did you drive a motor vehicle today?
☐ Yes ☐ No ***If no → skip to #31***

9. How many hours had you been awake when you began this drive? ________________

10. What the purpose of your drive? *(Select all that apply)*
☐ Commute to work
☐ Commute to home
☐ For work while on shift *(e.g., drive to patient home)*
☐ Errands *(e.g. store, appointment)*
☐ Leisure / social *(e.g., visit friends, gym/sporting, restaurant)*
☐ Family demands *(e.g., drive children, care for relatives, etc.)*

11. What time did you begin your most recent drive?
______________ AM / PM

12. How long was your most recent drive (minutes)?
_________hours ________mins

13. How busy was traffic during your most recent drive?
☐ Very busy (peak)
☐ Somewhat busy (moderate)
☐ Somewhat quiet (light)
☐ Very quiet (no traffic)

14. What was the weather condition during your drive?
(check all that apply)
☐ Snowy ☐ Cloudy/Overcast
☐ Icy ☐ Clear
☐ Heavy Rain ☐ Bright
☐ Heavy Fog ☐ Very sunny (glare)
☐ Light Fog

15. Did any of the following events occur during your most recent drive? *(check all that apply)*
☐ Startled awake in same lane
☐ Crossed the centre line into oncoming traffic
☐ Wandered into another lane
☐ Ran onto the "rumble strips" at edge of road
☐ Ran off the road
☐ Swerved violently
☐ Braked sharply
☐ Fell asleep at a stop light
☐ Resting your eyes
☐ Lack of awareness (e.g., 'daze')
☐ Memory gaps (e.g., unable to recall several km of drive)
☐ Fixation on interior/exterior object
☐ Being distracted
☐ Drove through a stoplight
☐ Missed intended turn or light signal
☐ Arrived at an unintended destination
☐ Another driver honked
☐ Shouting at another person
☐ Other (describe) ____________
☐ **None of these happened**

Sleepiness

Please rate your sleepiness *(using the 1-10 scale below)*

16. Start of Drive: ____ /10

17. End of Drive: ____/10

18. Maximum in drive: ____/10

1 - Extremely alert
2 - Very alert
3 - Alert
4 - Rather alert
5 - Neither alert nor sleepy
6 - Some signs of sleepiness
7 - Sleepy, but no effort to keep awake
8 - Sleepy, but some effort to keep awake
9 – Very sleepy, great effort to keep awake, fighting sleep
10 - Very sleepy, can't keep awake

19. Did you nod off *(i.e., head starts to nod briefly, difficulty keeping your head up) at the wheel while driving?*
☐ Yes ☐ No

20. Did you fall asleep at the wheel while driving, even if just for a moment?
☐ Yes ☐ No

21. Did you find yourself doing any of the following? *(Check all that apply)*
☐ Playing music
☐ Changing music often
☐ Reading
☐ Chewing gum
☐ Blowing cold air in face
☐ Using other gadgets
☐ Stopping car to rest
☐ Opening windows
☐ Mental occupation
☐ Using cell phone – text
☐ Using cell phone – call
☐ Using cell phone - apps
☐ Drinking caffeine
☐ Smoking
☐ Switching drivers
☐ Other- describe: _______________
☐ **None of these happened**

20. Did you wear sunglasses during the drive? ☐ Yes ☐ No

Near Miss

23. Did you have any 'near misses' on your most recent drive?
☐ Yes ☐ No* ***if No → Skip to #31***

24.What time did this near miss occur? ____________AM / PM

25. In what environment did this near-miss occur?
☐ Major highway (e.g., Hwy 401)
☐ Minor highway (e.g., Hwy 2, 7, 22)
☐ Secondary rural road (e.g., gravel, tar/chip, no lane markings)
☐ Suburban / Residential
☐ Urban / Downtown
☐ Commercial

26. Please describe the near-miss event & consequences to the best of your recall:
____
____

Crash

27. Did you have a 'crash' on your most recent drive?
☐ Yes ☐ No ***If no → skip to #31***

28. What time did this crash occur? __________AM / PM

29. In what environment did this crash occur?
☐ Major highway (e.g., Hwy 401)
☐ Minor highway (e.g., Hwy 2, 7, 22)
☐ Secondary rural road (e.g., gravel, tar/chip with no lane markings)
☐ Suburban / Residential
☐ Urban / Downtown
☐ Commercial

30. Please describe the crash events & consequences (e.g., injuries, vehicle/property damage) to the best of your recall.

____
____

Substances

31. In the past 12 hours have you used any of the following substances? *(Select all that apply)*
☐ Caffeine (coffee, tea, pop, energy drinks)
☐ Alcohol (wine, beer spirits)
☐ Cannabis (any mode)
☐ Prescription medications
☐ Over-the-counter medications
☐ **None of these* → skip to # 35**

32. Please estimate how many 12oz servings of caffeine-containing you consumed in the past 12 hours? *(Note: 12 oz is a standard medium hot drink, or can of soda)*
____

33. Please estimate how many servings of alcohol-containing drinks you consumed in the past 12 hours? *(Note: serving is a can/bottle of beer, 5oz glass of wine, or 1.5 oz of spirits)* ________________

34. Please describe cannabis consumed in the past 12 hours *(e.g., type of cannabis or relative THC/CBD content, mode of consumption, approximate amount, such as "1ml of high-CBD oil at 10pm")*
____
____

COMMENTS/NOTES

35. Do you have any other comments or notes about your driving today that you would like to share? ______________
____
____

Appendix G - Bivariate Correlation Matrix for Independent Variables

	Group	Age	Long. Shift	TST, Min 14-Day	TST, Percent <6h	PSQI Score	SE, 14-Day Avg	ESS Score	KSS Max 14-Day	KSS, Avg. 14-Day	rMEQ score	WFC, Time	WFC, Strain	1-Yr Sum Adv. Event	Cont. Drive Sleepy	DBQ, Full Average	OTMT-A, z-score
Group	1.00	-0.09	-0.76**	0.65**	-0.26	-0.42*	0.11	-0.19	-0.43*	-0.40*	0.36*	-0.55**	-0.38*	-0.23	-0.44*	-0.13	0.20
Age		1.00	0.22	0.10	0.14	0.03	0.21	-0.13	-0.27	-0.27	0.31*	-0.14	-0.12	0.14	-0.24	-0.22	0.47*
Long. Shift			1.00	-0.45*	0.37*	0.40*	-0.15	-0.11	0.26	0.24	-0.30	0.39*	0.31*	0.36*	0.30	-0.06	0.12
TST, Min 14-Day				1.00	**-0.51**	-0.34*	0.42	-0.26	-0.13	-0.09	0.22	-0.46*	-0.27	-0.07	-0.16	-0.11	0.23
TST, percent <6h					1.00	0.13	-0.47	0.06	-0.01	-0.06	-0.02	0.20	-0.07	0.07	-0.10	-0.25	0.14
PSQI Score						1.00	-0.04	0.00	0.34*	0.29	-0.23	0.17	0.20	0.11	0.12	0.07	0.02
SE, 14-Day Avg.							1.00	-0.02	0.00	0.01	0.12	-0.17	-0.15	0.00	0.16	-0.08	0.06
ESS Score								1.00	0.07	0.00	0.07	0.11	-0.04	0.16	0.28	0.32*	-0.13
KSS, Max 14-day									1.00	0.97**	-0.52**	0.21	0.30	0.23	0.44*	0.14	-0.14
KSS, Avg 14-Day										1.00	-0.57**	0.23	0.32*	0.10	**0.43**	0.16	-0.17
rMEQ score											1.00	-0.23	-0.35*	0.02	-0.17	-0.17	0.07
WFC, Time												1.00	0.71**	-0.15	0.37*	-0.08	-0.31*
WFC, Strain													1.00	-0.10	0.18	-0.14	-0.25
1-Yr Sum Adv. Event														1.00	0.31*	-0.04	0.11
Cont. Drive Sleepy															1.00	0.39*	-0.31*
DBQ, Full Average																1.00	-0.22
OTMT-A, z-score																	1.00

Notes: *Pearson's Correlation, N=42, Significance * = p < .05, ** = p <.001*

Appendix H - Multiple Linear Regression Model for Predicting 6-week Sum of Adverse Driving Events

Model	*B*	*SE*	*Beta*	*t*	*p*	*95% CI [LL, UL]*
Model 1						
Age	-.72	.13	-.58	-5.36	<.001*	[-1.00, -0.45]
Group	-11.81	2.97	-.46	-3.98	<.001*	[-17.88, -5.75]
PSQI Score	1.20	.34	.33	3.52	<.001*	[0.50, 1.90]
TST, percent of days <6h/24h	.09	.05	.18	1.70	.10	[-0.02, 0.20]
SE, 14-day average	-.03	.19	-.01	-.14	.89	[-0.40, 0.35]
ESS Score	.06	.40	.02	.16	.87	[-0.75, 0.87]
KSS maximum, 14-day average	-.44	1.02	-.04	-.43	.67	[-2.53, 1.65]
1-Year sum of adverse events	-.08	.07	-.10	-1.14	.26	[-0.23, 0.07]
Continue to drive when sleepy	-.09	.41	-.02	-.22	.83	[-0.92, 0.75]
DBQ Full Scale, average	2.80	3.83	.07	.73	.47	[-5.03, 10.63]
OTMT-A, *z*-score	-.14	1.12	-.01	-.12	.90	[-2.43, 2.16]
Model 2						
Age	-.73	.12	-.59	-5.99	<.001*	[-0.98, -0.48]
Group	-11.91	2.81	-.46	-4.23	<.001*	[-17.65, -6.16]
PSQI Score	1.20	.33	.33	3.59	<.001*	[0.51, 1.88]
TST, percent of days <6h/24h	.09	.05	.18	1.72	.10	[-0.02, 0.20]
SE, 14-day average	-.03	.18	-.01	-.14	.89	[-0.40, 0.35]
ESS Score	.07	.39	.02	.17	.87	[-0.73, 0.86]
KSS maximum, 14-day average	-.45	1.00	-.04	-.44	.66	[-2.49, 1.60]
1-Year sum of adverse events	-.08	.07	-.10	-1.16	.26	[-0.23, 0.06]
Continue to drive when sleepy	-.08	.40	-.02	-.21	.83	[-0.90, 0.73]
DBQ Full Scale, average	2.82	3.76	.07	.75	.46	[-4.87, 10.50]
Model 3						
Age	-.73	.11	-.59	-6.67	<.001*	[-0.96, -0.51]
Group	-11.96	2.74	-.46	-4.36	<.001*	[-17.56, -6.37]
PSQI Score	1.19	.33	.33	3.64	<.001*	[0.52, 1.86]
TST, percent of days <6h/24h	.09	.04	.18	2.15	.04*	[0.00, 0.18]
ESS Score	.06	.38	.01	.15	.88	[-0.72, 0.83]
KSS maximum, 14-day average	-.45	.98	-.05	-.46	.65	[-2.46, 1.55]
1-Year sum of adverse events	-.08	.07	-.10	-1.17	.25	[-0.23, 0.06]
Continue to drive when sleepy	-.10	.38	-.03	-.27	.79	[-0.87, 0.67]
DBQ Full Scale, average	2.98	3.51	.08	.85	.40	[-4.17, 10.14]
Model 4						
Age	-.74	.10	-.60	-7.05	<.001*	[-0.95, -0.52]

Group	-11.98	2.70	-.46	-4.44	<.001*	[-17.48, -6.49]
PSQI Score	1.19	.32	.33	3.70	<.001*	[0.54, 1.85]
TST, percent of days <6h/24h	.09	.04	.19	2.23	.03*	[0.01, 0.18]
KSS maximum, 14-day average	-.47	.96	-.05	-.49	.63	[-2.43, 1.50]
1-Year sum of adverse events	-.09	.07	-.11	-1.29	.21	[-0.22, 0.05]
Continue to drive when sleepy	-.09	.36	-.02	-.25	.81	[-0.83, 0.65]
DBQ Full Scale, average	3.15	3.28	.08	.96	.34	[-3.53, 9.83]
Model 5						
Age	-.74	.10	-.59	-7.17	<.001*	[-0.94, -0.53]
Group	-11.75	2.49	-.45	-4.72	<.001*	[-16.82, -6.68]
PSQI Score	1.21	.31	.33	3.89	<.001*	[0.58, 1.84]
TST, percent of days <6h/24h	.10	.04	.19	2.33	.03	[0.01, 0.18]
KSS maximum, 14-day average	-.51	.94	-.05	-.54	.59	[-2.42, 1.40]
1-Year sum of adverse events	-.09	.06	-.11	-1.46	.15	[-0.22, 0.04]
DBQ Full Scale, average	2.89	3.06	.08	.94	.35	[-3.33, 9.11]
Model 6						
Age	-.71	.09	-.58	-7.63	<.001*	[-0.90, -0.52]
Group	-11.21	2.26	-.43	-4.96	<.001*	[-15.81, -6.62]
PSQI Score	1.17	.30	.32	3.91	<.001*	[0.56, 1.78]
TST, percent of days <6h/24h	.10	.04	.19	2.43	.02*	[0.02, 0.18]
1-Year sum of adverse events	-.09	.06	-.11	-1.47	.15	[-0.22, 0.03]
DBQ Full Scale, average	3.00	3.02	.08	.99	.33	[-3.14, 9.13]
Model 7						
Age	-.73	.09	-.59	-7.88	<.001*	[-0.92, -0.54]
Group	-11.74	2.20	-.45	-5.34	<.001*	[-16.20, -7.27]
PSQI Score	1.17	.30	.32	3.90	<.001*	[0.56, 1.77]
TST, percent of days <6h/24h	.09	.04	.17	2.24	.03*	[0.01, 0.17]
1-Year sum of adverse events	-.10	.06	-.12	-1.54	.13	[-0.22, 0.03]
Model 8						
Age	-.70	.09	-.57	-7.58	<.001*	[-0.89, -0.51]
Group	-11.15	2.21	-.43	-5.06	<.001*	[-15.63, -6.68]
PSQI Score	1.13	.30	.31	3.71	<.001*	[0.51, 1.74]
TST, percent of days <6h/24h	.089	.04	.17	2.24	.031*	[0.01, 0.17]

Notes: B = unstandardized regression coefficient, SE = standard error, Beta = standardized regression coefficient, t = independent samples t-test, p = significance (= <.05), CI = confidence interval for unstandardized regression coefficient. PSQI = Pittsburg Sleep Quality Index Scale, TST = Total Sleep Time, SE = Sleep Efficiency, ESS = Epworth Sleepiness Scale, KSS = Karolinska Sleepiness Scale, DBQ = Driver Behaviour Questionnaire, OTMT-A = Oral Trail Making Test –A.*

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