A PROGRAM OF RESEARCH ADDRESSING EXPOSURE ASSESSMENT IN EPIDEMIOLOGICAL STUDIES OF SHIFT WORK

by

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Abstract

Background

Shift work is common with wide-ranging implications for worker health. It is also complex, presenting challenges for exposure assessment in epidemiological studies and the development of strong evidence to inform health interventions and policies. This dissertation generated new information on the *measurement, assignment*, and *determinants* of shift work exposure, in order to address important limitations in this field of epidemiology.

Methods

In Chapter 2, 152 full-shift personal light-at-night *measurements* were collected from 102 shift workers in emergency services and healthcare to investigate exposure variability and different exposure metrics. In Chapter 3, multiple exposure indicators were constructed for a national survey of nurses (n=11,450) to demonstrate the impacts of exposure *assignment* on observed relationships between shift work and depression. In Chapter 4, interviews were conducted with 88 employers in one Canadian province to examine *determinants* of workplace-level shift work policies and practices.

Results

In Chapter 2, average light-at-night exposures varied across occupations and settings; between-group variance exceeded between-worker and within-worker variance, and all exposure metrics were moderately-to-highly correlated. In Chapter 3, the strongest relationships between shift work and depression were observed in the model with highest exposure precision, defined by shift timing and rotation intensity, whereas weak relationships were observed in models with lower exposure precision, defined by shift timing or presence/absence of shift work. In Chapter 4, long duration shifts varied by industry and were more likely in large workplaces; shift work education/training was more likely in large workplaces and those without seasonal shift work; and nighttime lighting policies were more likely in workplaces reporting that maintenance, client service needs, or prior nighttime incidents affected shift work.

Conclusions

This dissertation can inform future epidemiological studies of shift work. Chapter 2 identified high-level exposure indicators (e.g., occupation groupings) and flexibility in the choice of highly correlated metrics for light-at-night exposure studies. Chapter 3 showed that increasing the precision of exposure assignment reduced measurement error and effect attenuation for the outcome of depression. Chapter 4 identified determinants of workplace-level shift work policies and practices (e.g., industry, employer size, temporary work, and employer motivations) to consider in future research and interventions.

Lay Summary

One third of Canadians perform shift work (something other than a regular daytime schedule). Shift work is linked to various physical and mental health outcomes, however strong evidence to clarify these relationships and inform health interventions has been slow to develop. One reason is that shift work "exposure" is complex and difficult to assess in health research, where risks are evaluated by comparing groups of people with differing amounts of exposure to a hazard.

This dissertation addressed three evidence gaps concerning the assessment of shift work exposure in health research. Chapter 2 measured and characterized light-at-night exposure levels of shift workers; Chapter 3 assessed how different definitions of shift work exposure affects researchers' ability to detect health effects; and Chapter 4 identified workplace characteristics that may determine certain types of shift work policies and practices. These findings should be considered in future studies of shift work and health.

Preface

The work presented here is that of the candidate, with usual guidance from the supervisory committee (Dr. Mieke Koehoorn, Dr. Hugh Davies, and Dr. Renee-Louise Franche) and manuscript co-authors. Additional contributions to the research are as follows:

For Chapter 2, Dr. George Astrakianakis at the University of British Columbia, Canada provided support with study design and recruitment. Dr. Mariana Figueiro, Dr. Mark Rea, and Mr. Geoffrey Jones at the Rensselaer Polytechnic Institute's Lighting Research Center, USA, provided scientific expertise and technical support with the study sampling equipment.

For Chapter 3, the Statistics Canada's Research Data Centres Program granted the candidate access to microdata from The National Survey of the Work and Health of Nurses, conducted by Statistics Canada and the Canadian Institute for Health Information.

For Chapter 4, the candidate's development of an updated survey and data collection protocols built upon a prior employer survey conducted in 2003 by Dr. Ralph Mistlberger and Dr. Glenn Landry. A graduate student (Ms. Andrea Smit, Simon Fraser University, Canada) assisted study management; two undergraduate students (Ms. Shannon Gahan and Ms. Meagan Ratz, Simon Fraser University, Canada) conducted the majority of survey interviews.

Identification, design, and performance of the research program

The candidate, with input and support from the thesis supervisory committee and manuscript co-authors, developed each study's research topic and research design.

For Chapter 2, the candidate conceptualized the research questions on light-at-night exposure, designed the study, and selected the exposure measurement tool. The candidate then carried out participant recruitment and data collection and conducted all data preparation and statistical analyses.

For Chapter 3, the candidate conceptualized the research questions on shift work exposure assignment and depression outcomes, designed the study, and applied for access to Statistics Canada microdata (The National Survey of the Work and Health of Nurses) via Statistics Canada's Research Data Centres Program. Once access was granted, the candidate conducted all data preparation and statistical analyses on site at the University of British Columbia (Vancouver campus)'s Research Data Centre.

For Chapter 4, the candidate conceptualized the research question on determinants of workplace-level shift work policies and practices, developed an updated survey, and established data collection protocols. The candidate then conducted participant recruitment in collaboration with the study manager, oversaw data collection by research staff, and conducted all data preparation and statistical analyses.

Publications

Three research chapters (Chapters 2 to 4) were written as manuscripts for publication in peer-reviewed journals. All outlines and drafts were prepared by the candidate and circulated for review by thesis committee members and manuscript co-authors as appropriate; one to two rounds of revisions occurred for each Chapter.

A version of Chapter 2 has been published. Hall AL, Davies HW, Koehoorn M. "Personal light-at-night exposures and components of variability in two common shift work industries: uses and implications for future research". Scand J Work Environ Health (Online-first) Sept 27, 2017; doi:10.5271/sjweh.3673. The candidate conceptualized the study, carried out all recruitment and data collection, conducted data cleaning and statistical analyses, interpreted results, and prepared the manuscript. The candidate's total contribution to the work as a whole was 90%.

A version of Chapter 3 is under peer review (September 2017). Hall AL, Franche RL, Koehoorn M. "Examining the effect of exposure assignment in epidemiological studies of shift work: a study on depression among nurses". The candidate conceptualized the study, performed all data cleaning and analyses, interpreted results, and prepared the manuscript. The candidate's total contribution to the work as a whole was 85%.

A version of Chapter 4 has been published. Hall AL, Smit AN, Landry GJ, Mistlberger RE, Koehoorn M. "Organizational characteristics associated with shift work practices and potential opportunities for intervention: findings from a Canadian study". Occup Environ Med 2017;(74):6-13. The candidate conceptualized the research questions for this study, led the design of a new employer survey, co-supervised data collection, performed all data analyses, and wrote the manuscript. The candidate's total contribution to the work as a whole was 70%.

Ethics Approval

Ethics approval for Chapter 2 was obtained from The University of British Columbia, Canada's Behavioural Research Ethics Board (Study Number H15-01720).

Ethics approval for Chapter 3 was obtained from The University of British Columbia Canada's Behavioural Research Ethics Board (Study Number H13-02137).

Ethics approval for Chapter 4 was obtained from Simon Fraser University, Canada (Study Number 2014s0337) and The University of British Columbia, Canada's Behavioural Research Ethics Board (Study Number H14-01588).

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List of Abbreviations

BC: British Columbia, Canada

NAICS: North American Industry Classification System

NSWHN: National Survey of the Work and Health of Nurses

SI: International System of Units

Glossary

Chronotype: The behavioural manifestation of underlying circadian rhythms

Circadian rhythm: A 24-hour cycle in the processes of living beings

Circadian disruption: Perturbations in endogenous circadian rhythmicity

Entrainment: The alignment of a circadian rhythm's period and phase to the period and phase of an external rhythm

Exposure assignment: The application of exposure categories or levels to epidemiological study subjects

Exposure indicator: A qualitative proxy for exposure (e.g., category or group) applied to epidemiological study subjects during exposure assignment

Exposure metric: A quantitative description of exposure (e.g., mean, median, 90th percentile)

Lux: A measure of light intensity as perceived by the human eye

Photopic illuminance: The density of light falling on a surface, described in units of lux

Zeitgeber: Environmental or social cue that synchronizes the processes of living beings to a 24-hour cycle

Acknowledgements

This PhD would not have been possible without the support and guidance that I received from many people.

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For the analysis of depression in nurses, I thank the Statistics Canada's Research Data Centres Program for granting me access to microdata from The National Survey of the Work and Health of Nurses. On-site technical support provided by Statistics Canada data analysts (Lee Grenon, Wendy Kei, and Cheryl Fu) at the University of British Columbia's Research Data Centre was much appreciated.

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Dedication

To Joan Budd, in memoriam.

Champion of nature, education, and logic;

always moving, thinking, questioning.

Chapter 1: Introduction and background

Up to the late 1800s, human activity was governed primarily by natural solar cycles of light and darkness. Modern society has introduced light into times and places where it does not naturally occur, allowing for work and social behaviours to extend beyond the solar day. "Shift work" generally aims to extend an organization's operational time beyond a regular 8-hour day, using a succession of worker teams (1). This has become a common form of working time; shift work is reported by a third of the Canadian workforce (representing over 4 million individuals) (2) and by up to 30% of other workforces globally (3).

Shift work enables extended or 24-hour activity in sectors where continuous services (e.g., law enforcement, healthcare, transport, telecommunications) or operations (e.g., power and water utilities) are essential (1). It is also used for economic reasons, such as to maximize cost efficiency in production and manufacturing (4). In recent decades, shift work has been increasingly relied upon to extend the provision of non-essential services (e.g., entertainment, restaurants, fuel, and shops) (1,4,5). The largest proportions of Canadian shift workers are located in trade, manufacturing, accommodation and food services, and healthcare and social assistance sectors (6); similar to the United States (7) and European countries (8). Women represent the majority of night workers in healthcare and social assistance, trade, and accommodation and food services sectors, whereas men represent the majority of night workers in manufacturing, business, building and other support services, and public administration (6).

The most prevalent types of shift work schedules are irregular shifts (shift changes that are usually prearranged one week or more in advance - for example, pilots) and rotating shifts (those that periodically change between days, evenings, and/or nights) (See Table 1.1). This is followed by regular evening shifts, regular night shifts, split shifts (two or more distinct work periods each day), and on call/casual shifts (no prearranged schedule – for example, substitute teachers). Between 1996 and 2011, the proportions of Canadian workers in regular day schedules decreased, while proportions of workers in irregular schedules and regular night shifts increased (9–11). The majority of Canadian shift workers (82%) work full-time (30 hours or more per week) (2).

Table 1.1: Type of work schedule reported at end of year, Canada[1,2]

	1996 %	2006 %	2011 %
Regular daytime schedule	68.4	65.6	66.1
Irregular schedule	9.7	11.0	12.3
Rotating shift	10.1	10.7	9.4
Regular evening schedule	5.3	5.5	4.7
On call	2.2	2.2	2.7
Regular night or graveyard shift	1.7	2.2	2.0
Other/don't know/refusal	1.6	1.9	1.7
Split shift	1.0	0.9	1.0

[1] *Population: Persons aged 16-69 years and had a job during the reference year and paid worker*
[2] *Sources: Survey of Labour and Income Dynamics (9–11)*

Despite its many economic and social benefits, shift work can disrupt daily personal rhythms of biology, physiology and behaviour, with negative implications for worker safety and health (3–5,12–17). Shift work-related injury and disease produce significant personal and economic burdens, such as workforce absenteeism, productivity losses, and increased use of health services (18). Research into shift work and its impacts on health is therefore an important, yet evolving, field.

A recognized challenge in this area of epidemiological and intervention research is that "exposure" to shift work encompasses a variety of different scheduling, work environment, social, and individual characteristics (19). This complexity tends to result in coarse exposure assessment and assignment that produces misclassification, weakens exposure contrast, and masks differences across groups (20,21). It is therefore not surprising that calls have been made to improve the quality of exposure assessment in epidemiological studies of shift work (21–24). Such activities are well justified, given the increasing prevalence of shift work (particularly irregular work) in Canada and internationally (25,26) and its preponderance in disproportionately susceptible groups such as young, lower-educated, and lower-income workers (27–30).

To address current evidence gaps and inform future exposure assessment methods in epidemiological studies of shift work, this dissertation includes a series of three distinct studies that investigated the *measurement* (Chapter 2), *assignment* (Chapter 3), and *determinants* (Chapter 4) of shift work exposure. Chapter 1 will provide a review of basic concepts, summarize challenges related to exposure assessment in epidemiological studies of shift work, and introduce research objectives for this dissertation. Following a summary of each study in Chapters 2, 3, and 4, Chapter 5 will summarize findings, discuss methodological considerations, and present recommendations for future research.

1.1 Shift work: biological, physical, and social concepts

This dissertation does not seek to systematically review the fields of circadian biology, lighting science, and work organization. However, basic concepts related to shift work-related exposures and health (circadian biology, exposure to light-at-night, work schedules, and pathways between shift work and health) are summarized in the following sections to provide the reader with a foundation to understand the studies herein.

Further, this dissertation aims to present general exposure assessment concepts for use in future epidemiological studies of shift work. While these broadly discussed concepts may apply to a number of health outcomes, only the outcome of depression will be thoroughly discussed (as the focus of the epidemiological study presented in Chapter 3).

1.1.1 Circadian biology and the role of light

Rhythms that follow the 24-hour cycle of light and dark are circadian. The biological processes of humans and many other living organisms operate on a circadian cycle. In mammals, a master clock resides in the suprachiasmatic nucleus, located in the brain's hypothalamus (31). The suprachiasmatic nucleus drives the circadian rhythmicity (clocks) of various downstream physiological processes, including the sleep-wake cycle, hormone release, cardiovascular function, and metabolism (32,33).

Humans are diurnal mammals, meaning they are naturally awake and active during daylight hours and resting/sleeping at night. The suprachiasmatic nucleus is synchronized to a 24-hour (circadian) cycle by a number of environmental and social cues called zeitgebers (33–35); the term “entrainment” describes the stable synchronization of the biological clock with its zeitgebers.

The strongest zeitgeber for the human circadian system is the sun’s 24-hour cycle of light and dark (36). Details of the mechanisms by which external light cues are translated into internal physiological signals have only recently been explained (37–39). In mammals, the zeitgeber light is detected exclusively by the eyes (40), where the retinas transduce light signals to the suprachiasmatic nucleus via specialized receptors called intrinsic photosensitive retinal ganglion cells (38). The suprachiasmatic nucleus in turn translates these light signals to coordinate the circadian rhythmicity of physiological clocks throughout the body (33,41), such as the sleep-wake cycle (42), metabolism (43,44), cardiovascular function (45), and hormone release (46,47).

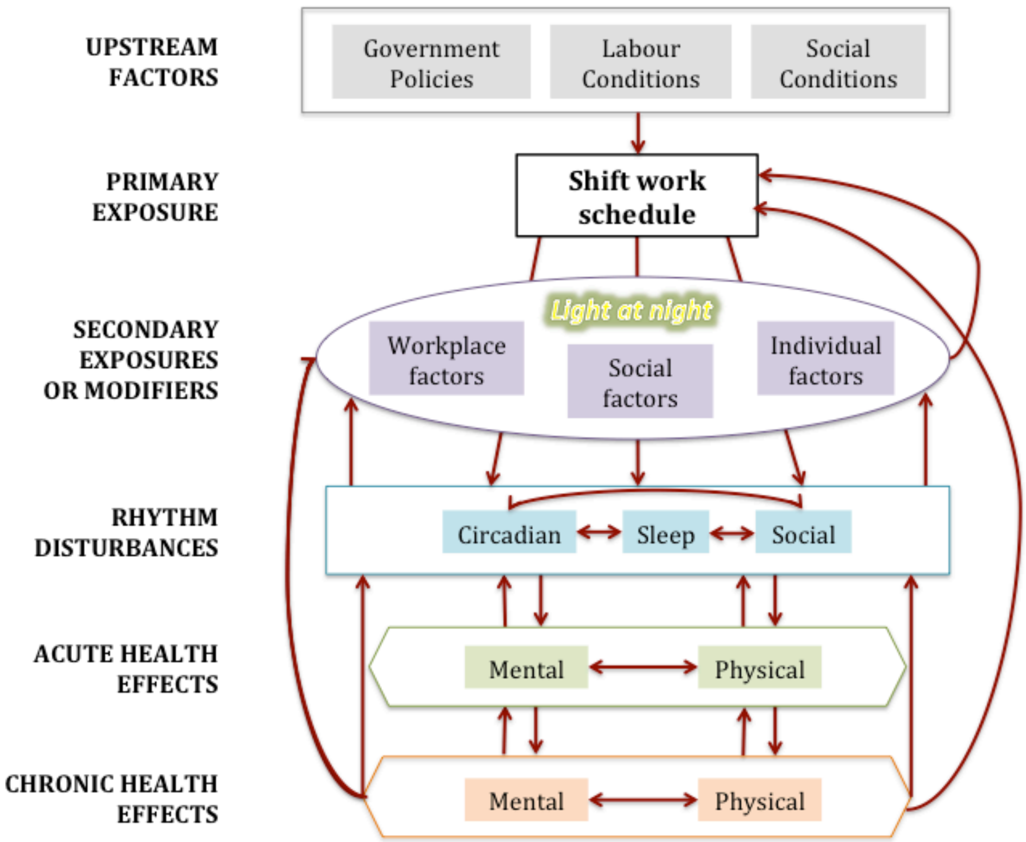
Melatonin is one important hormone that is produced and released by the pineal gland of mammals on a circadian cycle (48). Commonly described as the “biological marker of night”, melatonin’s circadian rhythm aligns closely with the natural light-dark period, with circulating levels lowest in daytime, increasing in the evening, peaking at approximately 4 am, and returning to near nil levels by late morning (49). The nocturnal release of melatonin into the blood and cerebrospinal fluid signals time of day information to cells, tissues and organs throughout the body (50); and circulating melatonin is widely regarded as the best biological index of circadian timing (51).

Perturbations in endogenous circadian rhythmicity (e.g., displacement of sleep relative to the circadian clock), particularly by exposure to artificial light during natural periods of dark, are defined as “circadian disruption” (52). This concept will be described further in section 1.1.2.4.

1.1.2 Conceptualizing factors related to shift work and its relationships with health

The structure and distribution of shift work is influenced by labour market and social conditions. In turn, shift work is associated with exposure to light-at-night and a number of circadian, sleep, and social disturbances that negatively impact on health. Pathways between these disturbances and health are strongly interconnected (34,42,52–54) and a number of exacerbating loops may feed back into an individual's work schedule (4). A conceptual model of the relationships between shift work and health, including upstream factors, intermediaries, and mechanisms, is presented in Figure 1 and discussed in the following sections.

Figure 1: Summary of factors related to shift work and its relationships with health



Adapted with permission (55)

1.1.2.1 Upstream factors affecting shift work

Shift work is a product of evolving social and labour conditions that have changed significantly in recent decades. In the UK and USA for example, recessions in the 1980s were followed by labour market de-regulation and large-scale replacement of traditional, relatively secure industrial jobs (conferring strong unionization and moderately sized salaries) with lower-paid work in the service economy (56). Women and older people represent increasing proportions of the workforce; part-time, flexible (e.g., freelancers), and multiple work arrangements are also on the rise (57). Increased labour market "flexibility" with less regulation by trade union agreements and employment laws has given employers greater leeway to offer insecure work and to structure working time as they see fit (56). Meanwhile, tightening rules for unemployment benefits has resulted in higher take-up of low-wage, insecure employment (56). Social inequalities in the quality of work, including the structure of working time, are well known. For example, workers with at least a postsecondary degree are less likely to report shift work, and workers in lower income households are more likely to report evening, night or irregular shift work (58).

1.1.2.2 Primary exposure: Shift work schedule

Organizations utilize a range of work schedules that vary widely by timing, duration, and frequency of work. This includes shift work, compressed work, overtime, part-time, flexible hours, and on-call work, among others. "Shift work" refers to a work system where one group of workers replaces another throughout the workday; a "shift worker" is typically defined as someone who regularly begins or ends work outside of daytime hours (1).

Shift work schedules vary considerably with respect to a number of features (54,59) that may influence their impacts on circadian rhythms, sleep, and social effects (60–62). These features include start and end times of shifts, rotation between shifts (including considerations of frequency and direction of rotation), duration of individual shifts, number of successive work days, number of successive shifts of a particular type, days of the week worked (weekday versus weekend), duration of rest between shifts, frequency and duration of breaks within shifts, regularity (or irregularity) of work schedule, amount of notice given before a shift, and an individual's control over their work schedule, among others (1).

Decisions concerning the design of shift schedules incorporate a number of factors, including (59):

- legislation (working time in Canada is mostly governed by general duty clauses laid out by individual provinces and in federally regulated workplaces);
- collective agreements (if the workforce is unionized);
- economic aims, e.g., varying consumer demand, maximizing use of equipment/facilities;
- labour market, e.g., availability of qualified workers and of full-time, part-time, or casual workers;
- characteristics of the workforce, e.g., age, caretaking or social responsibilities;
- physiological, psychological, and social recommendations based on current science about worker health, performance, safety, and well-being outside of work.

There are thousands of shift work schedules in use throughout the world, with no one optimal choice (59). Any schedule (including standard daytime work) may be problematic if it does not align with an individual worker's needs; however, some work schedules have a greater likelihood of being problematic. Research consensus on "best" scheduling practices in relation to health is generally lacking (60), particularly concerning long-term health outcomes (62). However, there is some agreement concerning scheduling practices to mitigate short-term effects. For example, night and early morning work (both requiring wakefulness during the natural sleep period) are generally considered to be the most disruptive to normal circadian functioning and sleep (21,59,61). Reductions in consecutive night shifts by increasing shift rotation speed are associated with improvements to sleep, reduced fatigue, and possibly improved work-life balance (60,62). Flexible working patterns to increase worker control, such as self-scheduling, are associated with positive health outcomes and decreased levels of sickness and disability absence (60,63,64), although little is known about the longer-term impacts of such interventions on sleep, alertness, and other health outcomes (22). Changing the direction of rotating shift patterns from backward (nights to days) to forward (days to nights) is associated with better physical and psychological well being, lower levels of chronic fatigue, and greater alertness at work (62,65,66), although this evidence base is not entirely conclusive (62,65). Further discussion of factors such as frequency of shift rotations and shift duration will be discussed in Chapters 3, 4, and 5.

In sum, while there may be no "ideal" choice of a work schedule, it has been argued that shift work should be structured to minimize disruption of circadian rhythms, avoid the accumulation of sleep deficits, and maximize regular social interaction (59).

1.1.2.3 Secondary exposures or modifiers: light-at-night and workplace, social, and individual factors

Light-at-night levels can be expected to vary across different work environments. Regulatory requirements for photopic illuminance levels in buildings typically incorporate issues of politics and economics (e.g., price of energy, source and cost of equipment) in addition to the needs associated with the structural environment in question (67,68). In the province of British Columbia, recommended workplace illumination levels are also based on safety requirements and task categories (69). This means that occupational light-at-night exposure levels may vary considerably across workplaces, occupations and job tasks. The impacts of light-at-night exposure on physiological responses differ across various lighting aspects (e.g., intensity, timing, and wavelength) (32,70). Light-at-night may also impact on individuals differently as a function of one's pupillary size (affecting the amount of light incident on the retinas) as well as age (increasing age is associated with decreased circadian responsiveness to light) (52,70).

Workplace factors are characteristics that apply equally to all individuals within an organization or site (71), such as lighting, availability of healthy food during both day and night, provision of rest areas for breaks (most available evidence suggests that naps on the night shift provide positive benefits in terms of subjective sleepiness and performance (72)), and company carpooling programs (to reduce the increased risk of motor vehicle accidents related to sleepiness and fatigue following night or long work hours (73,74)).

Workplace factors may also refer to psychosocial conditions within workplaces. The "psychosocial environment" has been defined as a socio-structural set of opportunities that is available to meet an individual's needs of well being, productivity, and positive self experience (75). Two important aspects of positive self experience are self efficacy and self esteem. Self efficacy is defined as an individual's belief in their ability to accomplish tasks;

this is often assessed using demand-control models to evaluate the combination of work demands with control over task performance (57). Self esteem is defined as the consistent positive experience of a person's self worth; this is often assessed using the effort-reward imbalance model to evaluate social reciprocity in the workplace (i.e., the extent to which employee efforts are reciprocated by equitable rewards) (57).

Other psychosocial conditions with potential impacts on health include staffing levels, safety culture and conditions, support from supervisors and colleagues, and work time control (4,76). In the field of shift work epidemiology, psychosocial conditions have received the most attention concerning their relationship to increased risks of cardiovascular disease (77) and mental health outcomes (78,79) in shift workers.

Additional *workplace factors* are physical job characteristics (e.g., noise, heat, dust, ergonomic tasks) (76,77) where exposures, or an individual's susceptibility to them, may vary across time of day worked (80). This was demonstrated in a nationwide survey of workplace exposures in New Zealand, where workers with non-standard hours were more likely to report exposure to all hazards assessed (exposure to dust, smoke or fume, gas, oils or solvents, acids or alkalis, fungicides, or other chemical products) than their regular daytime working counterparts (81).

Social factors describe potential interactions between a worker's personal and professional life, such as marital status and presence of children at home (19,82), the time required to commute to/from work (4), leisure time demands/activities (4), and home environment factors (e.g., daytime sleep environment, neighbourhood safety) (4,59).

Relative to regular daytime workers, shift workers are more likely to be single or previously married (2,58); in turn, marital status is strongly associated with an increased risk of mental health outcomes (the prevalence of major depressive disorder is lowest in married and highest in single and previously married Canadians) (83,84) and other health outcomes. Literature on health and mortality has consistently indicated that un-partnered individuals generally report poorer health and have a higher mortality risk than those that are partnered, with men being particularly affected (85).

Children add to domestic obligations and therefore contribute to difficulties in coping with shift work; this issue is especially problematic for women, although men are also affected (82). One large Canadian survey noted that males living in households with children were less likely to work shift than those without children, while there was no reported difference for female workers (58). However, female workers were more likely than men to report caring for family as their main reason for shift work (58).

Work/family conflicts are common in shift workers, since most family and social activities are organized according to daytime routines of the general population. This may negatively affect marital relationships and parental roles, and may also lead to increased sleep problems, chronic fatigue, and psychosomatic symptoms (80).

Leisure time to allow for renewal of mental or physical strength away from work is of less benefit when experienced in poor conditions (56). For example, commuting time to and from work can have a major impact on a shift worker's ability to rest and sleep between shifts (4). Shift workers who must sleep during the day may also be impacted by the nature of their home environment and non-work responsibilities (such as childcare). Recommendations to improve daytime sleep hygiene include the use heavy curtains to block out light, ensuring sound insulation of the home envelope, use of air conditioning, and sleeping in an adequate bed (71). Such measures are not feasible for all workers, particularly those who are economically disadvantaged and may face additional challenges such as lack of access to childcare or a safe home environment (4).

Individual factors that may affect shift work schedule's impacts on health include genetic, sex, and age differences in biological timing (24,82,86).

Humans differ from one another as to when their biological night starts and ends. In the absence of external zeitgebers, the intrinsic period of the human biological clock averages 24.18 hours (87). Inter-individual genetic differences affect the period length of this daily cycle, as well as the alignment of an individual's internal clock with external zeitgebers (e.g., time difference between sunrise and wake up, or between sunset and bedtime) (33). This effect describes differences in chronotype, with late chronotypes commonly referred to as “owls” and early chronotypes as “larks”. It has recently been argued that dichotomous “work at the civil night versus work at the civil day” comparisons are insufficient, since circadian disruption may not necessarily be caused when individuals work at night as defined by civil time (88). For example, owls may not experience circadian disruption when working during parts of the civil night, but may incur circadian disruption when working early shifts during the civil day (89).

Shift workers are younger relative to regular daytime workers (2,58). To some extent this may relate to age-related differences in chronotype. Chronotype is delayed in adolescence; reaching a maximum of “lateness” at approximately 20 years old; then becoming earlier again with advancing age (the peak of “earliness” occurs after 60 years of age) (33). This phenomenon, in combination with decreased duration and quality of sleep with advancing age (90), might explain older workers’ decreased tolerance for night work and long-duration shifts (91).

Sex and gender differences are also seen in shift work schedules and tolerance to night work (2,58). Women represent approximately 37% of all full-time shift workers and nearly 70% of all part-time shift workers in Canada (2). Women are more likely than men to work rotating shifts (41% versus 34%) and evening shifts (14% versus 10%), while men are more likely than women to work irregular shifts (35% versus 25%) (2). Males are on average later chronotypes than females (33); this could explain males’ relatively higher tolerance for shift work as demonstrated by better sleep and less fatigue and sleepiness at work, and a healthier lifestyle (24). Gender differences in total work time may also explain these differences in tolerance, since total weekly work time (paid plus unpaid) is consistently higher in employed women compared to men (92).

Pre-existing health conditions can also increase an individual’s susceptibility to negative impacts arising from shift work (93). Such conditions may relate to a higher risk health behaviour profile arising from or related to shift work, such as night shift workers’ increased odds of smoking, obesity, and low socioeconomic status (94,95).

1.1.2.4 Rhythm disturbances and health effects

The acute effects associated with shift work often mimic symptoms of jetlag (4), including fatigue, sleep disturbances, digestive problems, and impaired cognition and performance (96). The risk of acute work-related injuries also increases during night, evening, and early morning hours, relative to day work (97).

The chronic effects associated with shift work include increased risk of developing breast and other cancers (20,98,99), as well as cardiovascular (96), metabolic (100), and mood disorders (16,101). A discussion of the evidence for shift work's effects on mental health outcomes, such as mood disturbances and depression, is presented in Chapter 3.

Shift work and exposure to light-at-night can lead to various circadian, sleep, and social rhythm disruptions (21,102–104). These disruptions are thought to negatively impact health through a variety of pathways that are highly interconnected and difficult (if not impossible) to disentangle (32).

Both light-at-night and altered sleep can disrupt circadian rhythmicity in hormones, gene expression, metabolism markers, and a number of other physiological parameters (32,105), including melatonin production and release (46,106,107). Melatonin is involved in a number of human physiological and pathophysiological processes, such as cancer inhibition (50), immune function and vascular regulation (108). Melatonin also increases propensity for sleep at night (109), sleep duration, and sleepiness (48,110,111).

Sleep disturbances in shift workers are well documented (13,61,112–114). Working shifts is associated with future sleep disturbances, while termination of shift work is associated with fewer sleep disturbances (112). Poor sleep quantity and quality is in turn associated with impairments of cognitive and motor performance (leading to increased risk of workplace incidents) (115,116), and various chronic effects such as altered immune function (117), increased risk of cardiovascular and metabolic disorders (and associated mortality) (15,118–120), and depression (121). Disturbed sleep may also increase the likelihood of light-at-night exposure (e.g., insomnia leading to increased activity during the biological night).

Social de-synchronization arising from night shifts or other irregular work schedules can affect shift workers' participation in family, social, and cultural activities, resulting in both biological disturbances (e.g., gastrointestinal, cardiovascular, and sleep) (19,34,104) and psychological disturbances (e.g., increased work-family conflict, marital problems, and social isolation) (96,122) that may feed back into circadian and sleep disturbances (123,124). Changes in work organization over time have also altered the boundaries between home and work (25). Conflict between work and home demands, which appears to be particularly problematic for women (125,126), can lead to stress and negative health consequences (127).

1.1.2.5 Summary

There is no "one size fits all" solution to address the negative consequences of shift work; a highly variable exposure with a number of workplace, situational, and personal factors influencing its effects on health. The preceding section describes a number of pathways or mechanisms for how shift work may arise or vary within the workforce, and how shift work and its characteristics may impact health or modulate health effects. Since many of these pathways overlap and are difficult to disentangle, common upstream variables (the focus of this dissertation, i.e., work schedule and related exposures such as light-at-night), are reasonable exposure targets in epidemiological studies of shift work. This reflects a "stimulus-based" model approach, which describes shift work as a stressor that is a direct cause of disease, compared to a "transactional" model approach, which implies that variables aside from shift work are responsible for poor health (128). While transactional models tend to place responsibility for worker health on the individual as a target of change, stimulus-based models focus on environmental factors, thus shifting responsibility from the individual to the employer and society. In this way, stimulus-based research can be used to advocate for broadly applied interventions; this has been promoted as a more pragmatic and effective means of reducing shift work-related disease burden at a population level (129).

1.2 Exposure assessment challenges in epidemiological studies of shift work

Exposure assessment is an important factor in all epidemiological research seeking to identify, evaluate, and control health risks (130). In the epidemiological context, exposure assessment involves the identification of the hazard to be evaluated, collection of data, assignment of exposure indicators, and selection of appropriate metrics to estimate exposures (131). These activities are crucial to epidemiological studies, which evaluate health risks by comparing outcomes across differently exposed groups.

Generally, the term “exposure” refers to: (1) “proximity and/or contact with a source of a disease agent”, or (2) “the amount of a factor to which a group or individual was exposed” (132). In the first definition, exposure is simply regarded as an attribute that is either present or absent (“exposed” or “unexposed”). This simple dichotomy can (and should) be extended to include considerations of exposure quantity as outlined in the second definition, since exposure measures must be precise, accurate and appropriate for the study design, and biologically and temporally relevant (133) in order to avoid biased associations in the exposure-response relationship (134).

A common problem in studies of shift work, where exposure features are numerous and variable within and between individuals, is weak exposure assessment that does not appropriately capture characteristics relevant to risk of health outcomes (20–22). This leads to non-differential exposure misclassification; a type of information bias where misclassification is independent of the outcome and leads to a predictable underestimation of health effects when exposures are dichotomous, and an underestimation or overestimation of health effects when exposures variables have more than two categories (135).

While exposure assessment issues confront all areas of shift work and health research, studies investigating the carcinogenicity of shift work provide a good example of current limitations and the need for refinement. In 2007, the International Agency for Research on Cancer (IARC) classified shift work that involves circadian disruption as “probably carcinogenic to humans” (Group 2A), based on limited evidence in humans working night shifts, and sufficient evidence in animal studies assessing the carcinogenicity of light exposure during the biological night (3). The working group responsible for this classification noted "an important limitation of the available epidemiological studies is that there have not been clear and uniform definitions of 'shift work' used" (21).

For instance, most large epidemiological studies published to date on the topic of shift work and breast cancer have used coarse definitions of exposure to shift/night work that are not sufficient to properly assess the risk of shift work-related circadian disruption on cancer risk (20,21). Examples include assessment of exposure to shift work and night work primarily based on sporadic self-reports, or on membership in a work sector where shift work involves a high percentage of workers (e.g., using national registries). Reports of other quantitative and qualitative information describing shift schedules (such as number of night shifts worked per month or year, number of consecutive night shifts, direction and speed of rotation, and shift length) have often been missing or highly varied (20).

Since the IARC classification, shift work's causal role in the development of breast cancer continues to be vigorously discussed, particularly in cases where coarse exposure assessment is perceived to promote conclusions of "no effect" (136–142). For example, a recent paper by Travis et al. (136) described results from three prospective studies published since the IARC review, and provided an updated meta-analysis of findings from all prospective studies of shift work and breast cancer. Based on their findings, the authors concluded that "classification of night shift work as a probable human (breast) carcinogen is no longer justified" (136). While this conclusion was accepted by some (143,144), a number of researchers published critical responses to Travis et al.'s conclusions (137–139,145), pointing primarily to the likelihood of "severe exposure misclassification" (138) due to short follow up times, poorly characterized duration and intensity of exposure, and selection bias (137,138,140).

1.3 Rationale and objectives

Shift work is a common working arrangement with wide-ranging implications for worker health. While strong exposure assessment is an essential component of high-quality epidemiological studies, the complexity of this task is a recognized challenge in the field of shift work and health research. Various methodological challenges, particularly issues with exposure assessment, have limited the development of high-quality epidemiological evidence to inform strategies to mitigate shift work's negative impacts on health (21,23,80,146). A number of reviews, reports, and commentaries point to the need for more research in this area (20–23,32,62,147,148); many explicitly emphasize the need for more precise analyzes of exposure to shift work in epidemiological studies (20–23).

This PhD dissertation aimed to generate new information on the assessment of shift work exposure in epidemiological research, in order to address a number of limitations in this field. It includes a series of three distinct studies focused on issues concerning the measurement, assignment, and determinants of shift work exposure, as follows:

1.3.1 Measuring light-at-night exposure levels and characterizing variability in shift workers

Relationships between light and physiologic responses in humans and animals have been investigated in controlled laboratory experiments (106,149–152). This has led to the understanding that exposure to light-at-night has negative effects on human biology (153), and is likely a strong contributor to shift workers' increased risk for various biological and social disruptions (32,70,154,155).

While controlled setting studies can be very useful to identify relationships between shift work-related exposures and circadian disturbances, workplace-based research is required to make connections between scientific findings and "real-world" practices (156). An empirical understanding of occupational exposures to light-at-night is needed to plan efficient sampling strategies, to reduce misclassification and attenuation of exposure-response relationships in epidemiological studies (134), and to target at-risk worker groups for research and intervention purposes (157). However, an investigation of light-at-night exposure levels and variability within and between shift workers has not been conducted to date, and quantitative data describing occupational exposure to light-at-night are limited in number and quality (20,62,158). Furthermore, there are no standard (health-based) light-at-night exposure metrics available for use in epidemiological studies of shift work.

The objective of Chapter 2 is to measure personal exposures to light-at-night, and to assess variability and metrics of exposure, in a sample of emergency services and healthcare shift workers in the province of British Columbia, Canada.

1.3.2 Characterizing the impacts of exposure assignment in epidemiological studies of shift work

Exposure assignment (the application of exposure categories or levels to study subjects) is a fundamental consideration in an epidemiological study, since this is the basis for comparing health outcomes across groups with differing amounts (or types) of exposure to a hazard. The common use of coarse exposure indicators (e.g., "day worker" versus "night worker") in epidemiological studies ignores a number of potentially important exposure characteristics of shift work (e.g., shift timing, rotation frequency) that may impact on health (21). This trend is problematic, since coarse exposure assessment and assignment can produce measurement error and exposure misclassification within groups (134) that can attenuates effects and mask true exposure-response relationships. Progress in the use of detailed and consistent exposure assignment in shift work research has been widely called for, to improve the quality of epidemiological evidence in this area (20–24).

The objective of Chapter 3 is to characterize the impacts of exposure assignment on the relationship between shift work and depression in a national sample of nurses in Canada, by assigning and comparing exposure indicators with varying degrees of precision.

1.3.3 Identifying determinants of workplace-level shift work policies and practices

Modifiable workplace-level policies and practices that determine the nature of shift work exposures may contribute to the quality of a working environment for shift working employees (159). Information on determinants (e.g., workplace size, temporary work, and employer motivations) of workplace-level shift work policies and practices (e.g., work scheduling, lighting policies, and health education) could provide useful targets for epidemiological research and interventions. Such information could also promote a better understanding of the barriers and facilitators to conducting research and translating evidence into best practices within workplaces.

Empirical research into determinants of workplace-level shift work policies and practices has not been conducted to date. For example, while there is evidence to suggest that controlling exposure to light at night could help to mitigate the negative health effects and risks associated with shift work (160,161), the characteristics of workplaces that apply nighttime lighting policies have not been defined.

The objective of Chapter 4 is to describe and assess determinants of workplace-level shift work policies and practices thought to affect health, across a range of industry sectors, in a sample of shift work employers in the province of British Columbia, Canada.

Chapter 2: Personal light-at-night exposures and components of variability in two industry sectors where shift work is common

2.1 Introduction

Workplace exposures can vary across a number of factors, such as work content, tasks performed, production characteristics, and time (162). Information on exposure variability therefore provides an important scientific basis for exposure assessment in the planning, analysis, and interpretation of epidemiological studies (134,163). However, few empirical assessments of occupational light-at-night exposure levels have been conducted.

Exposure to light-at-night and circadian disruption arising from shift work can result in a lack of entrainment between natural lighting cues and workers' internal circadian rhythms (21), producing a number of physiological disruptions (164). Dose dependence between light-at-night intensity and human physiologic response has been noted in laboratory settings (106,149), but there has been limited measurement of light-at-night exposure in "real-life" settings (1), and the variability of such exposures has not been examined. The few occupational studies that have been conducted to measure light-at-night exposures have typically assessed effects on biomarkers in shift workers (20,165); focusing primarily on individual workplaces or occupations in healthcare, manufacturing, and public safety sectors (62). This is a noteworthy gap, since quantitative measurements are essential to informing questions about exposure variability, designing future studies, and permitting the exploration of exposure-response relationships (163).

In epidemiological studies, exposure measurements are used to estimate and assign exposures to workers (166). This can take two forms: individual assessment, where exposures are measured and assigned on a worker-by-worker basis; or grouped assessment, where subgroups of workers are formed based on factors such as occupation or work area/tasks that may affect exposure. In the latter case, a relative parameter of the group's exposure distribution is applied to all individuals within the group (134). Grouped exposure assessment implicitly assumes that all individuals within groups are uniformly exposed, although in reality, within-group variability is common. This potential source of exposure measurement error and misclassification is frequently ignored in classical statistical analyses of exposure-response relationships (134), leading to the possibility of attenuated risk estimates (163).

An exploratory study can be very useful for gathering the information needed to optimize exposure assessment strategies and to choose an exposure indicator that reduces the potential for measurement error (134,163). This should be done by assessing a representative sample of the study population, with participants chosen among all relevant exposure categories and repeated random sampling of individuals (134). An analysis of variance components within the smaller sample can then be conducted prior to undertaking a larger field study. This involves partitioning the total variance of exposures within a population into component parts: *between-worker* variance, a measure of variation in average exposure levels between workers; *within-worker variance*, a measure of temporal variation within individuals; and *between-group variance*, a measure of variation between exposure groups established by the investigator (e.g., occupation, workplace, industry) (167). An examination of variance components allows for an assessment of the degree and nature of exposure variability present, and consideration of the best exposure indicator (e.g., occupation, workplace, or industry) to optimize exposure assessment strategies (163). Such data can thus be helpful to inform decisions about who, where, and how many people to measure in an epidemiological study (168).

The selection of an appropriate exposure metric (quantitative description of an exposure) is also an important scientific consideration in exposure assessment, since observed exposure-response relationships can be sensitive to the metric chosen (134). Currently there are no standard (health-based) metrics available for use in epidemiological studies of shift work. In situations where the most biologically relevant exposure metric is unknown, the assessment of multiple measures can be useful (131). This approach has been demonstrated in other contexts, such as the assessment of various exposure metrics for peak occupational exposure to organic solvents (169). An evaluation of correlations between exposure metrics provides a better understanding of the limitations and strengths of data to evaluate exposure-response relationships (163).

2.1.1 Light concepts

Light is most frequently defined as the visible portion of the electromagnetic spectrum (i.e., wavelengths between 400 and 780 nm) (170). Photoreceptors (rods and cones) in human eyes collect, interpret, and transpose this range of electromagnetic waves into meaningful visual signals in the brain.

Light as it affects the visual system (photopic illuminance) is the basis for conventional photometry and for most commercially available light measurement devices. Photopic illuminance is described in units of "lux", that is, the density of light falling on a surface (1 lux = 1 lumen/m^2, where "lumen" is the unit of total visible light emitted by a source) (171). Simply put, lux is a measure of light intensity as perceived by the human eye.

Some light exposure thresholds have been proposed for human biological end points. Increasing light levels, measured in terms of photopic illuminance, have been shown to increase alertness (172). One study examining the dose-response relationship between illuminance and subjective alertness found that room light of ~100 lux elicited half of the maximum alerting response (that occurred at bright light of 9100 lux) (173). Increasing light levels measured in terms of photopic illuminance also affect human melatonin levels, with endogenous melatonin suppression beginning at light levels of ~30 lux for 1 hour (saturation occurring at ~1000 lux) (174). Therefore, multiple photopic illuminance metrics of biological relevance (median lux, 90th percentile lux, sum of minutes ≥ 30 lux, and sum of minutes ≥ 100 lux) may be useful to characterize shift workers' exposure to light-at-night for various health endpoints.

2.1.2 Study rationale and objectives

Measurements of workplace exposures are crucial for both the evaluation of possible health risks, as well as their reduction through control measures (157). Information on exposure variability provides an important scientific basis for exposure assessment in the planning, analysis, and interpretation of epidemiological studies (134,163).

For example, knowledge about exposures is useful for selecting samples with maximal exposure variability, thereby increasing sampling efficiency by minimizing the number of participants needed to achieve a certain level of study power (175). The use of an appropriate grouping strategy for assigning exposure indicators can also reduce the likelihood of exposure misclassification and distorted exposure-response relationships (166). Furthermore, empirical data that describe light-at-night exposures can be used to identify groups of shift workers at greatest risk of negative health outcomes, for use in targeted research and workplace prevention efforts.

Quantitative measurements of light-at-night exposures can be used for a number of epidemiological purposes. However, few empirical assessments of occupational light-at-night exposure levels and variability have been conducted. The current study measured shift workers' exposure levels to light-at-night to characterize occupational exposures and inform future exposure assessment methods. It aimed to answer the following questions:

1) What are the light-at-night exposures of shift workers in healthcare and emergency services, and do these exposures vary by industry and occupation?
2) What are the components of variance for light-at-night exposures (within-worker, between-worker, and between-group) across different exposure indicators and metrics?
3) What are the correlations between various light-at-night exposure metrics?

2.2 Methods

Data on light-at-night exposures were collected from shift workers in emergency services and healthcare industries employed by the Provincial Health Services Authority, within the province of British Columbia, Canada. These industries employ a substantial proportion of shift workers in British Columbia (the healthcare sector alone represents 15% of all night and rotating night workers in the province (10)) and were expected to represent a range of lighting conditions (68).

2.2.1 Equipment

For this study, personal measurements of photopic illuminance were collected using the Daysimeter (176), a small light monitoring device that has been validated (177) and used in prior studies to examine the impacts of light exposures on health (178–180). This device continuously records photopic illuminance levels from ambient light sources using an integrated circuit light sensor array (177,181).

2.2.2 Recruitment and data collection

Sampling was conducted between October 2015 and April 2016 in Vancouver area ambulance stations, in Vancouver and Victoria area emergency dispatch offices, and in the British Columbia Women's Hospital in Vancouver, Canada. Participants were emergency health services workers (paramedics and dispatch officers) and hospital workers (nurses, security guards, patient care aides, unit clerks, pharmacy and medical laboratory staff) working one or more overnight shifts that included the 23:00 to 05:00 period.

Purposeful sampling was conducted to capture workers in a range of occupations and environments within the aforementioned worksites. To permit calculations of exposure variance between and within workers, the recruitment aim was to sample 100 shift workers, with repeated measurements for up to 2 shifts per worker. At minimum 5 shift workers were recruited at each worksite. Additional information on recruitment is available in Appendix A.1.

The study coordinator (A. Hall) was present on site at the beginning of each participant's first sampling work shift to deliver the light sampling device and administer a short in-person training session. Each participant was instructed to wear his or her monitor on the upper chest (suspended from a lanyard) for the entire night shift. Photopic illuminance measurements were logged at a rate of one measurement per minute and downloaded at the end of each shift.

2.2.3 Study variables

This study examined four metrics of photopic illuminance between 23:00–05:00 hours for each participant shift. These were: median lux, to characterize central tendencies; 90th percentile lux, to characterize peak exposures; sum of minutes ≥30 lux, to characterize duration of exposure that may suppress melatonin production; and sum of minutes ≥100 lux, to characterize duration of exposure that may elicit half of the maximal alerting response.

2.2.4 Statistical analyses

All study participants worked overnight shifts that included the period from 23:00 to 05:00, with the exception of security guards who started their shifts at midnight. No distinct exposure patterns were noted across security guards' shifts by hour; therefore measurements from each security guard's 00:00-01:00 period were applied to the 23:00-00:00 period. This was done to retain security guards in the analytic sample, and to reduce the potential for underestimating their exposures in comparison with other worker groups across the 6-hour exposure window.

Summary statistics for each exposure metric were calculated by industry and occupation. Correlations among metrics were examined using Pearson correlation coefficients.

Data distributions for each exposure metric were examined using frequency distributions, probability plots, and skew and kurtosis values. The median and sum of minutes ≥ 100 lux exposure distributions were lognormal and, therefore, log-transformed for the components of variance analyses. The 90th percentile and sum of minutes ≥ 30 lux exposure distributions were approximately normal and were not transformed.

Each exposure metric was grouped by industry (2 groups), by workplace (4 groups), by work site (9 groups) and by occupation (10 groups), presented in Table 2.1. To identify each variance component's relative contribution to total variance, a series of random effects (or "null") models was generated using PROC MIXED in SAS (Version 9.4) (182). The first model included only worker as a random effect (Model 1); four subsequent models examined each grouping: worker + industry (Model 2), worker + workplace (Model 3), worker + worksite (Model 4), and worker + occupation (Model 5).

Table 2.1: Summary of grouping schemes for shift workers' personal light-at-night exposures (n participants, n measurements[1])

Industry	Workplace[2]	Worksite[3]	Occupation
Emergency Services (33, 47)	Call Centre (19, 30) Various (14, 17)	Call Centre - Vancouver (14, 22) Call Centre - Victoria (5, 8) Various - Surrey (9, 11) Various - Delta (5, 6)	Dispatch Officer (19, 30) Paramedic (14, 17)
Healthcare (69, 105)	Hospital Unit (58, 84) Hospital Other (11, 21)	Hospital Unit – LDR (23, 31) Hospital Unit – NICU (27, 34) Hospital Unit – Ward (12, 20) Hospital Other – Lab (5, 10) Hospital Other – Circ (6, 11)	Nurse (38, 56) Lab Technologist (2, 4) Lab Assistant (3, 6) Care Aide (11, 17) Security Guard (5, 9) Unit Clerk (4, 7) Pharmacist (4, 4) Respiratory Therapist (2, 2)
2 Groups	4 Groups	9 Groups	10 Groups

[1] *Maximum number of measurements per participant = 2*
[2] *Various = ambulance stations, hospitals, other indoor settings, and outdoor settings; Hospital Unit = Labour and Delivery, Neonatal Intensive Care, or General Ward; Hospital Other = Laboratory and non-fixed areas throughout hospital*
[3] *Various = ambulance stations, hospitals, other indoor settings, and outdoor settings; LDR = Labour and Delivery; NICU = Neonatal Intensive Care Unit; Lab = Medical Laboratory, Circ = Circulating*

2.3 Results

A total of 155 personal full-shift light-at-night measurements were obtained from 104 participants over 45 nights. Three measurements were excluded for technical (n=1) or compliance (n=2) reasons, resulting in a final analytic sample of 102 participants and 152 measurements. Repeated measurements on the same participant (n = 50, or 49%) were performed on average 11 days after their initial shift (range of 1 to 42 days).

Table 2.2: Personal light-at-night exposure averages (assessed in the 23:00 to 05:00 period)

	k	n	Median (lux)	90th percentile (lux)	Sum of minutes ≥ 30 lux	Sum of minutes ≥ 100 lux
Shift workers (all)	102	152	23	73	122	28
Healthcare (all)	69	105	29	88	151	36
Nurse	38	56	22	77	120	30
Care Aide	11	17	36	143	197	58
Security Guard	5	9	28	66	153	17
Unit Clerk	4	7	19	43	107	3
Laboratory Assistant	3	6	67	121	262	83
Laboratory Technologist	2	4	60	112	292	69
Pharmacist	4	4	30	97	178	40
Respiratory Therapist	2	2	14	38	94	6
Emergency medical services (all)	33	47	11	40	59	11
Dispatch Officer	19	30	8	12	15	1
Paramedic	14	17	18	88	137	28

k = number of workers
n = (number of workers) x (measurements shifts per workers) = total worker-shifts

2.3.1 Descriptive summaries

Average light-at-night exposures for the 23:00-05:00 period over all measurement shifts are presented in Table 2.2 by industry and occupation. Laboratory workers (technologists and assistants) and care aides displayed the highest levels for all light exposure metrics among shift worker occupations in the study. Emergency dispatch officers displayed the lowest levels for all light exposure metrics among shift workers.

Correlations between light-at-night exposure metrics are presented in Table 2.3. Correlations were generally high between all metrics (>0.657), but the highest correlations were observed between the median lux and sum of minutes ≥ 30 lux metrics (r = 0.893), and between the 90th percentile lux and sum of minutes ≥ 100 lux metrics (r = 0.810).

Table 2.3: Correlations between 4 light-at-night exposure metrics (n = 152 observations) assessed in the 23:00 to 05:00 period

	Median (lux)	90th percentile (lux)	Sum of minutes ≥ 30 lux	Sum of minutes ≥ 100 lux
Median lux	1.000			
90th percentile lux	0.657	1.000		
Sum of minutes ≥ 30 lux	0.893	0.759	1.000	
Sum of minutes ≥ 100 lux	0.755	0.810	0.691	1.000

2.3.2 Components of variance

Within-worker, between-worker, and between-group variances proportions for each grouping scheme across all exposure metrics are presented in Table 2.4. Between-group variance was large for all exposure metrics and increased as grouping precision increased (moving from industry to occupation). Within-worker variance was small for all exposure metrics and groupings, with the lowest values observed for median lux.

2.4 Discussion

This study measured light-at-night exposures in a sample of emergency services and healthcare shift workers. Personal light measurements were collected from participants across industries, workplaces, work units, and occupations, and repeated measurements were obtained on two separate night shifts for approximately half of participants.

2.4.1 Light-at-night exposure levels

Average light-at-night exposures for the 23:00-05:00 period varied significantly across industry and occupation. In the healthcare industry, the highest average levels for all exposure metrics were observed in laboratory workers (technologists and assistants) and the lowest average levels for all exposure metrics were observed in respiratory therapists and unit clerks. These results are consistent with recommended light levels for visual tasks associated with laboratory work activities (between 200 and 2000 lux) and recommended light levels in and around nursing stations (ranging from 20 lux in nighttime corridors up to 500 lux in general areas), where unit clerks and respiratory therapists in this study spent much of their time (68) (note that photopic illuminance measured at the cornea, or as proxy for the cornea, is substantially lower than photopic illuminance measured on the horizontal plane for lighting applications).

Table 2.4: Proportions of variance in 4 light-at-night exposure metrics across grouping schemes, accounted for by between-group, between-worker, and within-worker components (n = 152 observations) (assessed in the 23:00 to 05:00 period)

	Median (lux)[1]	90th percentile (lux)	Sum of minutes ≥ 30 lux	Sum of minutes ≥ 100 lux[1]
Model 1: No grouping - Worker random effect only				
Between-worker variance (%)	97.3	90.4	92.7	93.1
Within-worker variance (%)	3.7	10.6	8.3	7.9
Model 2: Industry (2 groups)				
Between-industry variance (%)	91.4	62.8	64.1	62.7
Between-worker variance (%)	5.6	25.8	27.6	29.5
Within-worker variance (%)	3.0	11.4	8.4	7.8
Model 3: Workplace (4 groups)				
Between-workplace variance (%)	93.2	70.7	78.9	75.3
Between-worker variance (%)	4.1	18.8	14.6	18.1
Within-worker variance (%)	2.7	10.5	6.5	6.6
Model 4: Worksite (9 groups)				
Between-worksite variance (%)	93.6	71.7	79.9	76.5
Between-worker variance (%)	3.6	17.4	13.7	17.1
Within-worker variance (%)	2.8	10.8	6.4	6.4
Model 5: Occupation (10 groups)				
Between-occupation variance (%)	94.6	80.1	85.8	81.5
Between-worker variance (%)	3.1	10.7	9.1	12.7
Within-worker variance (%)	2.3	9.2	5.1	5.9

[1] *Log-transformed*

In the emergency services industry, dispatch officers working in call centres displayed the lowest average lighting exposures across all light-at-night metrics for shift workers. This finding was expected, since study participants in these work environments expressed a preference for low general lighting levels during their overnight shifts. However, low lighting levels may not occur in night-time office settings beyond those studied here, given a range of recommended lighting levels for such environments (68) and personal differences in preferred lighting levels (183).

Depending upon the goals of the study or measurement strategy, light-at-night exposure measurements could be used to identify shift workers at greatest risk of fatigue (i.e., where light exposures are consistently low) or of melatonin suppression (i.e., where light exposures are consistently high during the natural darkness period).

Previous studies provide some opportunities for comparison with this study's light-at-night exposure level results. Median light levels of 38 lux between the hours of 00:00 and 05:00 were found in one Spanish study of workers from a variety of industries (including hospitals) (184). In Canada, researchers reported a mean light intensity of 7.2 lux (SD 6.73) between the hours of 00:00 and 05:00 for night shift nurses in one study (21) and a maximum of 37.2 lux for the same time period among nurses in a separate study (185). In the current study, the average median exposure for nurses (sampled in labour and delivery, neonatal intensive care, and low-acuity wards) between the hours of 23:00 – 05:00 was 22 lux, and for hospital workers overall the median was 29 lux. These results compare fairly well with the aforementioned studies, since distributions of light-at-night measurements, similar to other exposure measurements, are log normally distributed (186); therefore higher median lux levels are expected when compared to mean levels.

Regardless of work schedule, most people living in the modern age are exposed to light-at-night to some extent. Despite the unavoidable problem of assessing health risks in "exposed" shift workers against "unexposed" day workers (who are not truly unexposed) (32), it has been reasoned that night workers would have substantially higher exposures to light-at-night (21). To test this assumption and provide an exploratory comparison with the shift workers' light-at-night exposures, the current study collected light-at-night measurements from a small convenience sample of 13 daytime office workers employed within the same health authority as the participating shift workers. Very low average light levels were observed for all exposure metrics in this group (median lux = 1; 90th percentile lux = 2; Sum of minutes ≥ 30 lux = 2; Sum of minutes ≥ 100 lux = 1). This compares closely with other findings of low intensity light-at-night exposures in daytime workers, such as in a study of school teachers (99% of measurements taken between the hours of 00:00-04:00 < 1 lux) (179) as well as in daytime working nurses (between the hours of 00:00-05:00, mean lighting levels = 2.48 lux) (187). These results support the notion that on average, shift workers' light-at-night exposures in even the lowest categories (represented in this study by dispatch officers) exceed "background" light-at-night exposures of daytime working populations.

2.4.2 Components of variance

Exposure assessment strategies based on individual versus grouped measurement strategies each have benefits and disadvantages. Individual-based approaches generally increase precision of exposure-response relationships, but at the expense of introducing bias and effect attenuation (175). Grouped exposure assessment is commonly used in occupational epidemiological studies since data on individual exposures are often missing (in the case of historical exposures) or can be impractical/costly to collect (163). In addition to efficiency benefits, grouped exposure assessment can provide reasonably unbiased estimates of exposure-response relationships, since overestimation or underestimation of some group members' exposures produces less attenuation of an exposure-response relationship than would be produced when each individual is assigned the mean of their own exposure measurements (a Berkson error structure) (175,188).

This being said, the validity of a grouped exposure assessment approach relies on the assumption that individuals within assigned groups are similarly exposed (163), and that assigned groups provide sufficient exposure contrast (189). This assumption is not always true (163), as observed for a variety of occupational exposures where within-worker and between-worker exposure variability has been high relative to between-group variability for some exposure groupings (162,190–192).

Within-worker exposure differences are primarily driven by temporal variability (134), therefore the collection of repeated measurements for individual workers is needed to examine the degree and nature of such variability (163). The current study collected multiple measurements for 49% of participants, and observed low within-worker variability (ranging from 2.3% up to 11.4% of total variance) for all light-at-night exposure metrics. This differs from other studies that have demonstrated high within-worker variability for occupational exposures such as magnetic fields (190), dust (193), and mercury (192). The low within-worker variability in light-at-night exposure observed in this study is likely explained by the fact that many of the nighttime work environments assessed demand few lighting changes over time (e.g., call centres, hospital laboratories) and light-at-night levels are likely less affected by specific work tasks or activities compared to other occupational exposures. Another possible reason for the low within-worker variability observed is that comparisons of measurements collected over longer periods (such as a full shift) are more likely to be similar, compared to repeated shorter duration measurements (168,194).

Between-worker differences may arise from differences in job characteristics (e.g., work location, tasks) and personal characteristics (e.g., sex, age, body size, techniques used to carry out tasks). As workers are consolidated into smaller classification groups with fewer subjects, between-worker variability typically decreases and between-group variability increases (195). This study's light-at-night exposure variance components reflect this, with between-worker variance decreasing as classification groups become more precise (from large industry groupings to smaller occupation groupings). Between-group variance was lowest for industry (2 groups, 33-69 workers per group) and highest for occupation (10 groups, 2-38 workers per group) for all exposure metrics.

In this study, within-worker variance was low compared to both between-worker and between-group variance. The greatest contrast between groups was observed for the occupational grouping (across all exposure metrics assessed), and for the median lux metric (across all exposure groupings assessed). The median exposure metric for photopic illuminance exhibited the greatest between-group contrast for all exposure groupings, with up to 94.6% of variance explained by differences across occupations. The 90th percentile, sum of minutes ≥ 30 lux, and sum of minutes ≥ 100 lux exposure metrics also showed good contrast for the occupation grouping, with between-group differences explaining 80.1%, 85.8%, and 81.5% of variance, respectively.

Since residual classical error and attenuation in exposure-response are minimized when the ratio of between-group to within-group variability is large (134,188), the high between-group variability observed for all exposure groupings assessed in this study, particularly when using the median exposure metric, shows promise for future sampling strategies and exposure assignment in epidemiological studies. The information required to develop such groupings (e.g. occupation) is relatively easy to access and may prove to be a consistently efficient way of grouping light-at-night exposures to minimize within-group heterogeneity and therefore reduce exposure measurement error. The use of high-level groupings is also an important consideration regarding measurement burden, since night work is prevalent and individual-based assessments are not always practical due to financial or logistical constraints (166).

2.4.3 Exposure metrics

The selection of an appropriate exposure indicator for use in epidemiological studies has implications for observed associations between exposure and disease (166), however this decision is often not straightforward (131,166). Since toxicological mechanisms linking exposure to health outcome are not always fully understood, one recommended strategy is to evaluate multiple metrics, in order to increase the chance that the appropriate one will be used (131).

In this study, multiple light-at-night exposure metrics with potential biological relevance for epidemiological studies were constructed, and their correlations were assessed. The finding of moderate to high correlations between the four light-at-night exposure metrics (ranging from $r = 0.66$ to $r = 0.89$) indicates some consistency in exposures over a work shift and suggests that a number of metrics may be appropriate to assess similar aspects of light-at-night exposure, particularly for highly correlated metrics (e.g., use of median lux versus sum of minutes ≥ 30 lux, or use of 90th percentile lux versus sum of minutes ≥ 100 lux). Additional studies should be conducted to assess correlations between light-at-night exposure metrics and compare them to those observed in the current study.

Although multiple metrics of exposure may be used in situations where disease mechanisms are unclear, the choice of “best” exposure metrics should be based as much as possible on the conceptual nature of the research question, and on biological considerations of relationships between the exposure and the outcome in question (21,196,197). For example, cumulative exposure measures are commonly used in chronic disease studies whereas short duration (peak) exposure measures are often most appropriate to assess acute effects (169). A summary measure, such as median level, may be the most relevant exposure metric for studies examining the long-term effects of light-at-night and circadian disruption on health (21). The amount of time spent below or above a given illumination threshold (172,197) could be a more relevant metric for studies examining light-at-night’s effects on alertness and performance. Despite uncertainties about the “best” metrics to use in epidemiological studies, researchers are afforded a number of options in this regard, since current exposure monitoring equipment is relatively simple to use and permits the collection of light measurements over hours or even days.

2.4.4 Strengths and limitations

In this study, the measurement of light-at-night exposures in shift workers focused only on nighttime exposures at work. This could be viewed as a limitation, since an individual’s exposure to light throughout the 24-hour period can affect their circadian entrainment (and disruption) (198,199). Other research examining 24-hour patterns of light exposure in shift workers has been conducted (178,180) to examine the broader impacts of light on health. The objective of this study was to provide baseline data on light-at-night exposures and exposure variability *at work*, using various exposure grouping schemes and metrics. This information serves a different purpose, such as to inform sampling strategies that maximize exposure contrast in occupational studies of nighttime light exposures, or to develop exposure indices that take light-at-night exposure variability into account (e.g., assessing injury rates of shift workers employed across a variety of lighting environments). An additional benefit to assessing light-at-night exposure in the workplace is that broadly applied workplace interventions, such as lighting, offer the opportunity for systematic implementation and assessment for use in research.

The recruitment aim of this study was to capture measurements from a variety of occupations and work environments within two industries where shift work is common. Given the ubiquitous nature of light, it is unlikely that this study's results were affected by non-response bias (workers with higher or lower light-at-night exposure being more or less likely to participate). However, small measurement numbers within strata, or not enough strata, may have limited the amount of light-at-night variability captured. Future studies should be conducted to assess exposures in other industries, work sites, and occupations, where exposure levels and characteristics within and between workers may differ.

Since the longest period between repeated measurements in this study was 42 days, within-worker variability in light-at-night exposures could increase over longer time periods (e.g., due to occupational, architectural, and engineering changes). It should also be noted that only 49% of participants were repeatedly measured, with a maximum of two full-shift samples obtained per participant. Since repeated measurement rates varied across occupations (0% for pharmacists and respiratory therapists, up to 100% for laboratory workers), these estimates may not reflect the full extent of within-worker variability for all occupations reported. Despite this limitation, it should be noted that the nighttime lighting environments for occupations that lacked repeated measurements (pharmacists and respiratory therapists in neonatal intensive care) appeared to be equally or less dynamic compared to the nighttime lighting environments for other occupations where a high number of repeated samples were obtained (e.g., care aides and nurses).

A strength of this study's sampling strategy is that data were collected from shift workers not commonly captured in epidemiological research (e.g., laboratory staff, unit clerks, security guards) in addition to more commonly assessed occupations (e.g., nurses, paramedics). These findings do not necessarily apply to other shift work industries and workplaces where lighting environments may be different or more temporally varied. If a wider range of workplaces were included, total exposure variability would likely increase, and the relative contribution of each variability component could change. In practical terms the latter issues may be moot, since prior to any epidemiological study a small pre-investigation of exposure variability is recommended to guide an optimal exposure assessment strategy and reduce the potential for measurement error (134,163).

The mixed modelling methods used to assess components of variance incorporate several assumptions. It was assumed that light-at-night measurements were normally distributed and independent, and that within-subject variance was equal for each worker. Between-subject variance was also assumed to be equal for all groups of workers. The distributions of light-at-night metrics assessed in this study were either approximately normal or, in the case of lognormal distributions, were log-transformed prior to analysis. Participants were selected using a stratified approach with random sampling within strata, and repeated measurements were taken 11 days apart on average, so the majority of observations may be assumed to be independent. Within-group and within-worker variability in light-at-night measurements was not perfectly equal across groups or workers, however the grouping variables accounted for the majority of variability in all cases.

2.5 Conclusions

This study represents a first step to evaluating personal light-at-night levels and variability in industries where shift work is common. Results demonstrate the feasibility of assessing full-shift light-at-night exposures in a variety of shift workers, and indicate that light-at-night exposures in shift workers exceed those of day workers. An examination of exposure variability components suggests that high-level light-at-night exposure indicators (e.g., grouping at the level of occupation) could provide a simple yet relatively precise way of characterizing individual light-at-night exposures in future epidemiological studies of shift work. A number of biologically-based light-at-night exposure metrics were considered and may be useful in future epidemiological studies, including median lux, 90th percentile lux, sum of minutes ≥ 30 lux, sum of minutes ≥ 100 lux. The most closely correlated measures were median lux and sum of minutes ≥ 30 lux ($r = 0.893$), and 90th percentile lux and sum of minutes ≥ 100 lux ($r = 0.810$); the selection of "best" metric depends upon the conceptual nature of the research question and its specific biological hypotheses. Given the early stage of epidemiological research into the effects of light-at-night exposure on health, the relative ease of collecting exposure measurements, and the need to clarify mechanisms linking exposures to health outcomes, researchers may wish to investigate multiple exposure indices and metrics in future studies.

Chapter 3: Examining the impacts of exposure assignment in a study of shift work and depression among nurses

3.1 Introduction

"Exposure misclassification" describes an error whereby the assignment of an exposure level or category to an individual does not appropriately reflect their true exposure to a given agent. Many studies investigating shift work have used crude exposure categories when assessing health risk, such as the binary "shift work-exposed" or "not shift work-exposed" (20). Such categorizations ignore a number of exposure characteristics (e.g., shift timing, intensity, rotation frequency) that may have a bearing on health outcomes (21,23).

This is problematic, since crude exposure assessment and assignment can produce measurement error and exposure misclassification within groups (134), often leading to low exposure contrast and attenuation of true effects. The impact of exposure misclassification is illustrated by a large Swedish cohort study that examined the effects of shift work on the risk of myocardial infarction (200). When shift work was defined as "not day work", the Standardized Mortality Ratio (SMR) was 115% (95% CI: 104-126), whereas when shift work was defined as "night shift", the SMR increased to 148% (95% CI: 112-191) (23).

Despite this evidence and other calls to dissuade the practice (21,22,24,80), coarse categorizations are still commonly used to describe exposures in studies of shift work and health. In an effort to further clarify the impact of exposure misclassification in epidemiological studies of shift work, the current investigation sought to examine associations between shift work and depression.

Major depressive disorder is experienced by 5% of the Canadian adult population annually (201) and represents a significant source of disability and economic burden (202). While shift work has been linked to an increased risk of mental disorders such as anxiety and depression (16,96,101), these relationships and their explanatory mechanisms have not been well characterized. This topic requires further investigation, since there is increasing interest in the prevention of depressive disorders globally (203) and workplace risk factors may provide a useful target for depression strategies (204).

3.1.1 Hypothesized pathways between shift work and depression

Mood in healthy individuals can vary across the 24 hour cycle due to a combination of circadian and sleep influences; typically showing a deterioration in evening compared with morning hours (31,123,205). A number of physiological and social pathways may link shift work exposure with pathological mood and depression outcomes, including exposure to light at night, disrupted circadian rhythms (including sleep and melatonin) and altered social functioning (206,207).

Exposure to light at “abnormal” times in the circadian cycle has been associated with depressive-like behaviours in mice (208,209) and mood disorders in humans, such as seasonal affective disorder and major depression (31). While it is established that exposure to light plays an important role in modulating mood, the mechanisms behind such relationships are not well understood (210). Proposed pathways between light exposure and mood disorders include light’s effects on the timing of circadian cycles (for example, circadian alterations in melatonin release are implicated in a number of physiological processes related to mood, circadian entrainment, and sleep (50,53)), as well as light’s more direct impacts on sleep via the eyes’ retinal receptors (210).

Sleep disturbances are the most widely reported circadian disruptions associated with depression (31); individuals suffering from insomnia are more likely to have a depressive illness, with longitudinal research showing that persistent insomnia is associated with new depressive episode onset (121). Sleep disturbances in shift workers are well documented (13,61,112–114), with termination of shift work associated with decreased sleep disturbances and working shifts associated with increased future sleep disturbances (112). Working night shifts and early morning shifts appears to be most strongly associated with acute sleep loss (211); further, exposure to light-at-night may directly suppress sleep (212) and disrupt the normal sleep-wake cycle (153).

The social zeitgeber theory postulates that stressful life events may trigger depressive episodes by causing disruptions in social routines, leading to altered biological rhythms (207). Shift work has been linked to disruptions in social and family life patterns (213), and dissatisfaction with work-life balance is particularly pronounced in shift workers reporting split, on call or casual, or irregular schedules (2). Since a lack of social support is an important risk factor for depressive disorder (214), shift work's effects on social patterns may represent an important pathway to depression.

3.1.2 Prior research into shift work and depression

Evidence linking shift work with an increased risk of negative mental health outcomes is mixed, perhaps owing somewhat to the positive effects of work in general for mental health and well-being (215) versus the negative effects of sub-optimal work conditions for mental health (216). However, few studies have sought to investigate shift work's effects on depression, and as identified herein, even fewer have used refined measures of shift work for investigating exposure-response relationships.

A British household panel survey found that working varied shifts (with no usual pattern) was related to increased risks of anxiety/depression and minor mental disorders in females over time, but years' duration of night work did not show strong effects for these outcomes; whereas for males, years' duration of night shifts, but not varied shifts, increased risk of anxiety/depression and minor mental disorders over time (16). Another prospective cohort study found an increased risk of depressive disorder in current or former female shift workers versus never shift workers in adjusted analyses; no strong relationships were noted in current or former male shift workers (101). Finally, a short prospective cohort study of nurses found no strong relationships between working nights and working rotating shifts and independent measures of anxiety and depression (78).

In a cross-sectional study of hotel workers, an elevated risk of depression was observed in all shift worker categories relative to regular day workers (217). In another small cross-sectional study of nursing assistants, regular evening and rotating shift work were associated with an increased risk of depressive disorder whereas night work showed a protective effect (with all confidence intervals spanning "1") (218).

It should be noted that the exposure indicators assigned in all of these studies were either dichotomous: "night work" or "varied shifts" versus "none" (16), "shift worker" versus "never shift worker" (101), or incorporated considerations of shift timing only: "permanent night shift", "day and evening rotating shifts", or "day, evening, and night rotating shifts" versus "permanent day shift" (78); "rotating day shift", "rotating night shift", or "fixed night shift" versus "fixed day shift" (217), "evening shift", "night shift", or "rotating shift" versus "day shift" (218). Furthermore, the frequency of shift rotations (referring to the number of shift changes in a given time period) was not incorporated into the exposure assignment of any of these studies.

This is an interesting gap, since shift rotation frequency could be an important exposure characteristic to assess in studies of shift work and mental health. A high shift rotation frequency increases the likelihood of "quick returns" between shifts (i.e. changeovers from morning/day to night shifts, night to evening shifts, or evening to morning/day shifts where 11 hours or less of free time is scheduled between shifts (219)). Quick returns, identified as a "big problem in life" by some shift workers (220), have been associated with poor sleep quality, increased fatigue, and disrupted social relationships (221). High shift rotation frequency may also reflect precarious employment situations (222) that have been associated with increased social disruption, stress, and depressive symptoms (223–225).

Nurses, the largest occupational group in Canada's health sector, experience particularly high rates of depression. In a recent large representative survey, 9% of both male and female nurses experienced depression in the previous year (226), compared to 6% of all employed females and 3% of all employed males in the general working population (227). Nurses also reported higher rates of shift work in the survey, with 54% of respondents working something other than a regular day shift (226) compared to 28% of the general working population (2).

Depression is strongly linked to work absence (202,228,229). Healthcare workers, particularly nurses, experience high rates of work absence compared to other Canadian industry sectors (226,230). Interestingly, quick returns between shifts have been noted to be more common in healthcare versus other industry sectors (220); providing one possible explanation for the higher rates of depression and sickness absence seen in this worker population.

3.1.3 Study rationale and objectives

In a recent meta-regression examining the epidemiology of depression in Canada between 1994 and 2013, both the incidence and duration of major depressive disorder were found to be steady over time (231). Since many work related variables associated with psychological ill health and work absence are potentially amenable to change (232,233), the identification of modifiable workplace factors related to depressive outcomes (such as shift scheduling) could play an important role in reducing the burden of this prevalent disease.

The National Survey of the Work and Health of Nurses (NSWHN), 2005 (234) is a nationally representative cross-sectional survey that was conducted by the Canadian Institute for Health Information and Statistics Canada to provide a picture of the health and working conditions of nurses in Canada. The NSWHN collected a wealth of information on work scheduling, workplace characteristics, and health variables compared to most other large-scale surveys. Importantly, it also collected information on frequency of shift rotations; an exposure characteristic that is rarely described in other studies of shift work and health.

The NSWHN offered a unique opportunity to investigate the impacts of exposure misclassification on relationships between shift work and depression among nurses (a large working population with high prevalence of both shift work and depression) by using exposure indicators with varying degrees of precision. This study was particularly interested in examining relationships between shift rotation frequency and depression, since this had not previously been done. The hypotheses were:

(A) Associations between shift work schedule and depression will strengthen as the precision of exposure indicators increases, defined as: 1) High precision, considers shift timing and rotation frequency, 2) Moderate precision, considers shift timing only, and 3) Low precision, considers the absence/presence of shift work only; and

(B) Shift workers involved in regular night work and high frequency rotation shift work (the latter being a uniquely detailed measure of rotating shift work) will show higher odds of depression relative to regular daytime workers.

3.2 Methods

3.2.1 Data source

Data for this study were obtained from the National Survey of the Work and Health of Nurses (NSWHN), 2005, via Statistics Canada's Research Data Centres Program. The Research Data Centres program provides access to the microdata or master files of a select number of Statistics Canada Surveys, in secure settings that govern all aspects of data access from analysis through to publication of analytic output (235).

The NSWHN was a one-time survey dedicated to assessing the working conditions and health of nurses at a national level. The target population was regulated nurses (registered nurses, registered psychiatric nurses, and licensed practical nurses) aged 21 years or older who were registered and employed in Canada at the time of survey. To construct the sampling frame, Statistics Canada received membership lists from all nursing organizations and regulatory bodies in each of the 10 provincial and 3 territorial jurisdictions in Canada. From a national total of 331,992 nurses, 24,443 were selected at random using a stratified design to ensure adequate sample sizes for each jurisdiction and for each type of regulated nurse (registered nurse, licensed practical nurse, and registered psychiatric nurse). Within these strata, secondary stratification was conducted for age group, place of work (hospital, long-term care facility, community health setting, and other) and employment status (full-time, part-time, and casual). Computer assisted telephone interviewing was carried out by trained interviewers between October 2005 and January 2006 to obtain a survey sample size of 18,676 (response rate = 79.7%). Further details of the NSWHN survey measures, methodology, and quality control methods have been reported by Statistics Canada (234).

3.2.2 Study sample

To increase the precision of exposure indicators based on working conditions and health in the 12 months prior to survey interview, and to enhance the comparability of exposure-response relationships across exposure indicator categories, the analyses excluded individuals who were (1) employed in more than one nursing job (n = 2,846), (2) not exclusively providing direct care to patients or residents (n = 3,222), (3) employed in their current position for less than 12 months (n = 209), (4) temporarily absent from their nursing position for 12 months or more at time of interview (n = 104), and (5) self-employed (n = 295). The sample was further restricted to individuals with valid responses for the outcome variable, primary explanatory variable, and all other variables included in the analyses. These criteria produced an un-weighted sample size of n = 11,450 respondents.

3.2.3 Study variables

The outcome variable was major depressive disorder occurring within the 12 months prior to interview. To identify major depressive episodes, the NSWHN interview utilized a predictive instrument called the Composite International Diagnostic Interview Short Form, Major Depression section (CIDI-SFMD), developed by Kessler and colleagues (236,237). Depression categories for this study were dichotomized into "Yes" (respondent indicates 5 or more major depression symptoms on the CIDI-SFMD) and "No" (respondent indicates fewer than 5 major depression symptoms on the CIDI-SFMD). Prior validation studies have indicated that 75 to 90% of participants reporting 5 or more major depression symptoms on the CIDI-SFMD (approximating symptoms listed in the Diagnostic and Statistical Manual of Mental Disorders, 3rd Edition (DSM-III-R) criteria for major depression (238)) have had a major depression episode in the preceding 12 months (237,239). The full list of symptoms is reported in Appendix B.

The primary explanatory variable was shift work schedule. Three groups of exposure indicators for shift work schedule were derived from questions pertaining to work hours at respondents' main job: "Do you usually work days, evenings, or nights?" and (for the high precision definition only) "In the past 2 weeks, how many times did you change shifts (for example, from days to evenings, or evenings to nights)?"

Exposure Grouping 1 - High Precision Shift Work Schedule**,** seven categories (considers shift timing and rotation frequency):

A) Regular Days
B) Regular Evenings
C) Regular Nights
D) Slow Rotating Shifts (0-1 shift changes in past 2 weeks);
E) Medium Rotating Shifts (2-3 shift changes in past 2 weeks);
F) Rapid Rotating Shifts (4+ shift changes in past 2 weeks);
G) Undefined Rotating Shifts (did not work in past 2 weeks; could not be classified).

Exposure Grouping 2 - Moderate Precision Shift Work Schedule**,** four categories (considers shift timing only):

A) Regular Days
B) Regular Evenings
C) Regular Nights
D) Rotating Shifts

Exposure Grouping 3 - Low Precision Shift Work Schedule, two categories (considers absence/presence of shift work only):

A) Regular Days
B) Any work outside of regular daytime hours (regular evenings, regular nights, or rotating shifts)

Additional variables

The National Survey of the Work and Health of Nurses asked a number of questions about socio-demographic, health, and work characteristics, including psychosocial work factors that have been linked to depression (240). Since this study's goal was to measure the relationship between shift work schedule and depression, only variables with the potential to confound this relationship (but unlikely to lie on the causal pathway) were sought for inclusion in the models. Determinants or risk factors for depression, that are not associated with shift work and therefore not confounders of the relationship under investigation, were also excluded from the analyses. This was done using a priori knowledge and causal diagrams (241) to conceptualize relationships between variables.

Psychosocial work factors (e.g., high psychological demands, low social support) may be implicated in the aetiology of depression (79,242,243). All psychosocial work variables available in the survey (job strain, role overload, autonomy, control, psychological demands, social support, organizational support, and scheduling flexibility) were entered individually into a preliminary logistic model of depression and work schedule (high precision definition) to identify the strongest potential confounders for retention in the final model. Only autonomy, organizational support, and scheduling flexibility produced a substantial (>10%) shift in the point estimates for the effect of work schedule on depression. Examination of cross-tabs and Pearson chi-square tests showed strong interrelations between these three variables, so only scheduling flexibility (conceptually the least likely variable to be driven by shift work schedule, thus least likely to be on the causal pathway) was retained.

The following additional variables were included in the models as potential confounders since they are risk factors for depression and other mental health outcomes, and may also be related to work schedule: age (244,245), sex (246), family/living situation (245), socioeconomic status (245,246), presence of chronic health conditions (245,247,248), scheduling flexibility (249), workplace type (250), overtime (251), and typical shift durations (252) (see Table 3.1 for detailed categories).

3.2.4 Statistical analyses

Analyses were conducted through the Statistics Canada's Research Data Centres Program (235) at the University of British Columbia, using SAS Version 9.4 (182). All bivariable cell sizes were 30 observations or more, as required for confidential microdata release by Statistics Canada. To appropriately account for the NSWHN sampling procedures (234), probability survey weights provided by Statistics Canada were applied in all analyses to produce variance estimates that adjusted for the sampling strategy and reduced bias in the estimates obtained. In the final models, estimates were bootstrapped using 500 replicates as per Statistics Canada guidelines.

Crude odds ratios with 95% confidence intervals were calculated for the relationship between shift work schedule and depression. Logistic regression was conducted to assess the presence and strength of a relationship between shift work schedule and depression while adjusting for all previously stated confounders. Individual models were run for each shift work exposure indicator group (high, moderate, and low precision).

3.3 Results

3.3.1 Descriptive summaries

The distribution of study variables within the study sample (n = 11,450) is provided in Table 3.1. Over 60% of respondents reported something other than a regular daytime schedule. Outside of a regular day schedule (38.4% of respondents), the most frequently reported schedules were slow (20.1%) and medium (15.4%) rotating shifts. Depression was observed in 9.1% of the study sample's respondents, similar to the overall survey finding of 9.4%. Depression was most prevalent in respondents working rapid rotating shifts (13.8%), and in those who reported rotating shifts but who had not worked in the 2 weeks prior to the survey (12.7%).

Table 3.1: Baseline study sample characteristics and bivariable associations with depression (within previous 12 months): National Survey of the Work and Health of Nurses (NSWHN), 2005[1]

	Frequency (n = 11,450)	(%)	Depression % No	Depression % Yes
Depression				
No	10,446	90.9		
Yes	1004	9.1		
High Precision Shift Work Exposure Grouping				
Regular Days	4310	38.4	90.7	9.3
Regular Evenings	874	8.6	89.9	10.1
Regular Nights	899	9.7	91.4	8.6
Slow Rotating Shifts	2514	20.1	92.8	7.2
Medium Rotating Shifts	1919	15.4	91.3	8.7
Rapid Rotating Shifts	535	4.1	86.2	13.8
Undefined Rotating Shifts	399	3.4	87.3	12.7
Moderate Precision Shift Work Exposure Grouping				
Regular Days	4310	38.4	90.7	9.3
Regular Evenings	874	8.6	89.9	10.1
Regular Nights	899	9.7	91.4	8.6
Rotating Shifts	5367	43.2	91.2	8.8
Low Precision Shift Work Exposure Grouping				
Regular Days	4310	38.4	90.7	9.3
Shift Work (regular evenings, regular nights, or rotating shifts)	7140	61.6	91.1	8.9
Sex				
Female	10694	94.7	91.0	9.0
Male	756	5.3	89.4	10.6
Age (years)				
Less than 35	2131	20.5	91.5	8.5
35-44	3063	27.8	89.8	10.2
45-54	3973	34.3	90.4	9.6
55 and over	2283	17.5	93.0	7.0
Family/Living Situation				
Living with spouse/partner	3153	24.9	92.8	7.2
Unattached living alone	1514	13.3	88.4	11.6
Living with spouse/partner + children	4885	44.8	91.8	8.2
Other	1898	17.1	87.8	12.2
Household Income[2]				
High	10548	94.5	91.1	8.9
Low	902	5.5	87.4	12.6

	Frequency (n = 11,450)	(%)	Depression % No	Depression % Yes
Chronic Health Conditions[3]				
None	3693	33.9	94.7	5.3
1 or more	7757	66.1	89.0	11.0
Employment Type				
Permanent, Full-time	6407	56.9	91.0	9.0
Permanent, Part-time	3459	31.0	90.7	9.3
Non-Permanent, Full-time	497	3.6	90.0	10.0
Non-Permanent, Part-time	1087	8.5	91.5	8.5
Scheduling Flexibility[4]				
Yes	3154	27.3	92.0	8.0
No	8296	72.7	90.5	9.5
Workplace Type				
Hospital	5936	66.1	91.2	8.8
Long-term Care Facility	2879	16.3	90.1	9.9
Community	1669	10.7	90.5	9.6
Other	966	6.9	90.7	9.3
Paid Overtime[5]				
Yes	3481	33.5	89.8	10.2
No	7969	66.5	91.5	8.5
Typical Shift Duration				
8 hours or less	7026	62.8	90.1	9.9
12 hours or more	3646	31.3	92.1	7.9
Various	778	6.0	92.9	7.1

1 All percentages weighted to account for NSWHN probability sampling; values may not add up to 100% due to rounding.

*2 **Household Income**: categories modelled after Statistics Canada methods* (58), *based on 2 questions: "What is your best estimate of the total income, before taxes and deductions, of all household members from all sources in the past 12 months?" and "Number of people in the household". Low household income = (1-2 people; income <$30,000) or (3-4 people; income <$40,000) or (5+ people; income <$60,000); High household income = (1-2 people; income ≥$30,000) or (3-4 people; income ≥$40,000) or (5+ people; income ≥$60,000). Note: Donor imputation was used in the NSWHN for 7% of respondents who did not state their household income* (234)*.*

*3 **Chronic Health Conditions**: Derived variable including only long-term conditions that have or are expected to last 6 months or more, and that have been diagnosed by a health professional: allergies, asthma, fibromyalgia, arthritis or rheumatism, back problems, migraine headaches, diabetes (non-pregnancy related), heart disease, cancer, stomach or intestinal ulcers, bowel disorder (such as Crohn's disease or colitis), thyroid condition, chronic fatigue syndrome, multiple chemical sensitivities. Respondents indicating yes to one or more of these conditions were assigned yes for this variable.*

*4 **Scheduling Flexibility**: Based on the question "Does your employer offer flexibility in the hours nurses can choose to work?" Respondents indicating "No" or "Don't know" were assigned no for this variable.*

*5 **Paid Overtime**: Based on the question "How many hours of paid overtime do you usually work per week?" Respondents indicating zero hours were assigned no for this variable.*

In terms of potential confounding variables, the majority of respondents were females in the high household income category, with one or more chronic health conditions, employed in permanent full-time work, working in hospital settings, and with typical shift durations of 8 hours or less. Nearly half of respondents reported living with a spouse/partner and children. Approximately one third reported some degree of flexibility in their work hours, and working overtime every week, respectively.

3.3.2 Logistic regression

Associations between the three shift work exposure indicator groups and depression are presented in Table 3.2. Only the model using the high precision group showed strong associations between type of shift work and depression. The adjusted odds ratio for depression was higher in the rapid rotating shifts category (OR = 1.51, 95% CI = 0.91-2.51) and in the undefined rotating shifts category (OR = 1.67, CI = 0.92-3.02), while it was lower in the slow rotating shifts category (OR = 0.79, 95% CI = 0.57–1.08). No strong relationships emerged between shift work schedule and depression (OR range 0.95-0.99; Table 3.2) in the adjusted models using moderate precision and low precision shift work schedule indicator groups.

For the other potentially confounding variables, the strongest relationships with depression were observed in the 35 to 44 year old category (relative to 55 years old and over); in unattached individuals living alone and those with "other" family/living circumstances (relative to those living with a spouse or partner); and in those reporting one or more diagnosed chronic health conditions (relative to those reporting no diagnosed chronic health conditions). Higher odds ratios for depression were also observed for other younger age categories, for males, for those with low household incomes, for those with shorter (8 hours or less) shift duration, for those working some weekly paid overtime, and for those reporting no scheduling flexibility; the 95% CIs for all of these estimates included '1'. These relationships were consistent across all models (low, moderate, and high precision).

Table 3.2: Unadjusted and adjusted logistic regression odds ratios (ORs) and confidence intervals (CIs) modeling depression = yes, National Survey of the Work and Health of Nurses, 2005

	Unadjusted OR	*95% CI*		*Adjusted OR*[1]	*95% CI*	
High Precision Shift Work Exposure Grouping						
Schedule						
Regular Days	*Ref*			*Ref*		
Regular Evenings	1.09	1.03	1.15	1.00	0.70	1.43
Regular Nights	0.91	0.86	0.96	0.96	0.63	1.45
Slow Rotation	0.75	0.72	0.79	0.79	0.57	1.08
Medium Rotation	0.92	0.88	0.97	1.00	0.71	1.40
Rapid Rotation	1.55	1.45	1.66	1.51	0.91	2.51
Undefined Rotation	1.42	1.31	1.53	1.67	0.92	3.02
Sex						
Female				*Ref*		
Male				1.28	0.84	1.96
Age Group						
55 and over				*Ref*		
45-54				1.50	1.09	2.06
35-44				1.77	1.27	2.46
Less than 35				1.42	0.98	2.05
Family/Living Situation						
Living with spouse/partner				*Ref*		
Unattached living alone				1.66	1.16	2.38
Living with spouse/partner + children				1.00	0.74	1.33
Other				1.62	1.19	2.20
Household Income						
High				*Ref*		
Low				1.30	0.95	1.76
Chronic Conditions (diagnosed)						
None				Ref		
1 or more				2.29	1.74	3.00
Employment Type						
Permanent, Full-time				Ref		
Permanent, Part-time				1.10	0.86	1.41
Non-Permanent, Full-time				1.04	0.56	1.92
Non-Permanent, Part-time				1.06	0.72	1.55
Scheduling Flexibility						
Yes				Ref		
No				1.19	0.92	1.53

	Unadjusted OR	*95% CI*		*Adjusted OR[1]*	*95% CI*	
Workplace Type						
Hospital				Ref		
Long-term Care Facility				1.08	0.84	1.38
Community				1.10	0.79	1.53
Other				1.17	0.76	1.78
Paid Overtime						
No				Ref		
Yes				1.20	0.95	1.52
Typical Shift Duration						
12 hours or more				Ref		
8 hours or less				1.29	0.98	1.69
Various				0.87	0.52	1.44
Moderate Precision Shift Work Exposure Grouping						
Schedule						
Regular Days	Ref			Ref		
Regular Evenings	1.09	1.03	1.15	0.99	0.69	1.42
Regular Nights	0.91	0.86	0.96	0.95	0.63	1.44
Rotating Shifts	0.93	0.90	0.96	0.99	0.75	1.29
Low Precision Shift Work Exposure Grouping						
Schedule						
Day Worker	Ref			Ref		
Shift Worker	0.95	0.92	0.98	0.98	0.77	1.25

[1] Bootstrap weights applied; models adjusted for sex, age, living/family situation, household income, chronic health conditions, employment type, scheduling flexibility, workplace type, paid overtime, and typical shift duration

3.4 Discussion

The high precision shift work schedule exposure grouping used in this study divided the sample into 7 categories of shift work: regular day (38.4%), regular evening (8.6%), regular night (9.7%) and rotating work based on shift changes in the past two weeks: 0-1 (20.1%), 2-3 (15.4%), 4+ (4.1%), and undefined (3.4%). For the moderate precision shift work schedule exposure grouping, the latter categories were aggregated to form one rotating category that represented 43% of the total sample. For the low precision shift work schedule exposure grouping, all categories of non-regular daytime work were further aggregated into one shift work category that represented 61.6% of the total sample.

As hypothesized, the strongest relationships between shift work schedule and depression are observed in the high precision shift work schedule exposure model that considered elements of shift timing and rotation frequency. The odds ratio for depression was higher in the rapid rotating and the undefined rotating shifts categories, and decreased in the slow rotating shifts category. No relationship was observed with depression for the low and moderate precision shift work schedule exposure indicator groups.

While the bootstrapped high precision shift work schedule model results are not statistically significant in that the 95% confidence intervals include the OR value of '1', it is worth noting that confidence intervals are intended to serve as a general guide to the amount of random error in the data rather than as a literal measure (253). The point estimates presented for the high precision shift work schedule model are stronger than those obtained for the medium- and low-precision models. Odds ratios close to '1' are noted in the moderate precision shift work schedule exposure grouping that considered elements of shift timing only, and in the low precision shift work schedule exposure grouping that dichotomized shift work exposure into yes/no categories. The observed elevated odds for depression for the work schedule variable in the high precision model persisted after adjustment for confounders.

The elevated odds ratio for depression in this study's rapid rotating shifts category is a new finding, but consistent with reports from other emerging research. Rapidly rotating shifts may reflect precarious employment situations (work involving temporary, contract, or casual on-call positions that often lack benefits and job security; also referred to as "casual", "seasonal", "temporary", "non-standard" or "contingent" work) (222). Workers in precarious employment often experience unexpected changes in work schedule, and have little advance notice of their work schedule (254). Short notice (< 1 month) of a new work schedule has been linked to negative social effects in shift workers (220). Precarious employment and job insecurity have been associated with a number of related detriments (222), including increased social disruption, stress, and depressive symptoms (223–225).

Rapidly rotating shifts are also likely to increase the likelihood of quick returns (i.e. where 11 hours or less of free time is scheduled between shifts (219)). Some shift workers view quick returns as being more problematic than night work (220); with recent evidence showing that quick returns have negative effects on sleep and fatigue (255–257) and risk of sick leave (258). In these studies (255–258), the negative effects of quick returns were more severe than those of night work.

The preceding evidence on quick returns could explain the lack of strong relationships noted between regular night shift work and depression in this study. A body of strong evidence shows that night work is linked to increased risks of circadian disruption and negative health outcomes (3,259), and some studies have noted associations between regular night shifts and depressive outcomes (16,217). However, it is possible that social issues related to rapidly rotating shift schedules represent an equally strong (or stronger) link to negative mental health outcomes in shift workers, as compared to circadian disruption associated with night work. Rapidly rotating schedules may impose a greater mental strain on workers than regular night work, particularly in cases of irregular work schedules. In Canadian workers for example, dissatisfaction with work-life balance is most pronounced in shift workers reporting split, on call or casual, or irregular schedules (2). This could also explain the decreased odds ratio for depression noted in the slow rotating shift schedule category; rare or occasional changes in shift timing (0-2 times per month) are likely to be more predictable and may even confer greater work-life balance relative to regular daytime workers.

The increased odds ratio for depression in the undefined rotating shifts category (individuals not working in the 2 weeks prior to survey) is not straightforward to interpret. Depression is associated with temporary work leave and work impairment (202,228,229,245), therefore one explanation of the increased odds ratio for depression in this group is that depression status (unrelated to shift work schedule) resulted in the reported work absence. Another possibility is that the characteristics of workers' rotating schedules (e.g., high frequency rotations and associated stressors) resulted in depression and sick leave, as has been observed elsewhere (101). A third (though least likely) possibility is that respondents not working in the past two weeks were off work for reasons unrelated to depression, but were coincidentally more depressed than other respondents. Since the NSWHN's cross-sectional design lacks the temporal detail needed to assess which scenario is most likely, this study's finding of high depression outcomes in the workers with undefined rotating shifts should be interpreted with caution.

3.4.1 Strengths and limitations

In addition to precise and hypothesis-driven exposure assessment and assignment, the accurate estimation of exposure-response relationships relies on the control of variables that may confound the relationship between primary exposure and outcome. In this study's multivariable models, the observed relationships between shift schedule and depression persisted after adjustment for a number of known and potential confounders available in the NSWHN. The relationships observed between these confounders and depression are consistent with a body of research that has found higher rates of depression among younger adults (244,245), single or previously-married individuals (245), low income earners (245), and those with chronic health conditions (245,247,248). Low control over work time (relating to low scheduling flexibility) (249), long working hours (relating to overtime) (251), and shorter shift durations (252) also have been respectively linked to negative mental health outcomes, providing additional face validity to the models in the current study.

It is interesting to note that depression prevalence was higher in males than females in this study's sample, unlike general population surveys where depression prevalence is consistently higher in females (84,244). Higher depression prevalence in males in nursing populations has been observed in other studies (260,261) and may be explained by greater physical demands placed on male nurses (261), or by the disproportionate emotional effects of lower-prestige "female-type" occupations on male nurses relative to their female counterparts (262).

To reduce the likelihood of exposure misclassification, this study's analyses were restricted to individuals working one nursing job, since shift work schedule information was collected for respondents' "main nursing job" only. However, this study's shift work categories do retain some degree of misclassification, since the NSWHN does not differentiate between rotating shift work involving nights versus rotating shift work that involves only days and evenings. Furthermore, the NSWHN does not capture other exposure characteristics such as direction of shift rotations (60,65), history of shift work, and individual morning/evening preference (89) that may be important to consider when assessing the impacts of shift work schedule on depression. The current study's findings support the importance of assigning detailed shift work exposure indices in order to identify effects where they exist, underlining the need to collect and utilize such variables in future studies.

The relatively homogenous nature of NSWHN respondents reduced sources of residual confounding that are often present in general population surveys, such as differences in work environments and tasks that may impact on depressive outcomes (263). The NSWHN's size also permitted the restriction of analyses to nurses working in direct care areas and not self-employed, further reducing unmeasured differences in exposures between comparison groups and the potential for a biased assessment of the relationship between shift work schedule and depression. Although useful for the purpose of these analyses, the sample's homogeneity does introduce the possibility that the findings do not apply to other occupations and work environments, where the type and timing of work demands may have different impacts on depression.

A widely acknowledged challenge in shift work research is the self-selection of individuals in to and out of shift work (the "healthy worker effect") leading to a workforce of shift workers that is healthier than day workers (23) and biasing results toward underestimated effects. Workers that have remained employed ("survived") in shift work for long periods are likely less sensitive to its negative effects, which may also bias results towards the null. Self-selection *into* shift work (primary selection) may be less of a problem in nurses, since most direct care areas require some degree of night work, particularly for new graduates. Self-selection *out of* shift work (secondary selection) is likely a bigger issue affecting this study population. Recent longitudinal studies have shown that the presence of depressive symptoms (101) and other depression-related outcomes (264) at baseline is associated with a change in work schedule (leaving night work). In the present study, depressed workers who had moved from night work into a regular day schedule could have diluted the reference category and produced attenuated associations. Despite this, a relationship between work schedule and depression was observed when the high precision exposure grouping was used. It seems less likely that depressed individuals would differentially move into more disruptive schedules (i.e. rapidly rotating work) that would be required to overestimate the strength of association between shift work schedule and depression in this category of workers.

The NSWHN's cross-sectional design and lack of information on history of shift work did not allow for a temporal assessment of self-selection effects. Therefore, it is certain that some amount of misclassification was present in the "day worker" category (i.e., some former shift workers would be classified as day workers). Despite this important limitation, the NSWHN's stratified random sample sampling ensured representation across age categories which is an improvement over other studies of shift work that have assessed disproportionate numbers of middle- or advanced-age participants (136,146). The assessment of a short-latency health outcome may have also minimized the effects of self-selection out of shift work (i.e., shift workers recently affected by depression may not have moved out of a night work schedule at the time of survey). Although this study could not conduct a thorough investigation of healthy worker bias, this is an important methodological issue to consider in future research into shift work (23,265).

In an attempt to limit the effect of self-selection out of shift work in the current study, the sample included respondents who had not worked in the past two weeks prior to the survey, as well as those who were off work for less than one year at the time of survey. Individuals who were off work for more than one year at the time of study were excluded to permit the assessment of both shift work schedule and depression occurring in the past 12 months. This exclusion criterion could have resulted in an underestimation of depression prevalence and biased associations towards the null, although this effect may be minimal since the prevalence of depression in this sample (9.1%) is essentially the same as that reported in the full survey (226). The NSWHN's high response rate provides further assurance that error due to differences between respondents and non-respondents was relatively low.

This study's exposure and outcome measures are based on self-reports that were not validated against objective data, or by clinical assessment. Concerning the exposure measure, the validity of self-reported shift work exposure was recently examined in a Finnish study that compared self-reports to payroll registry data (266). Self-reported work involving night shifts (regular and rotating) showed greater sensitivity and precision than shift work not involving nights; imprecise reports of shift work not involving nights (e.g., shift workers that rotated between day and evening shifts identifying themselves as day workers) resulted in a bias towards the null when assessing work schedule's effects on fatigue (266). In the NSWHN, the type of rotating shift work (involving nights versus no nights) was not differentiated. Since the majority of respondents (62.8%) in the current study indicated 8-hour shift duration, rotations between day and evening shifts without any night shift work likely occurred in a (unknown) number of workers, and may have produced a bias towards the null when assessing relationships between shift work schedule and depression.

Concerning the validity of the outcome measure, the CIDI-SF assessment tool used to evaluate the likelihood of Major Depressive Disorder in the NSWHN was derived from a subset of items from the Composite International Diagnostic Interview (CIDI), a well-validated (237,239) WHO-endorsed tool that has been used successfully in other studies. Social desirability bias (arising from the stigma attached to mental illness) may have produced an underreporting of depressive symptoms as noted in another large general population health survey conducted in Canada (267), although this would likely be non-differential across shift type and would therefore exert a conservative bias on the exposure-response relationship.

Prior to the NSWHN, information available on Canadian nurses was deemed insufficient to conduct comprehensive, reliable, and valid evaluations of work and health (268). Although data collection for the NSWHN was conducted over a decade ago, this survey remains the largest and most detailed source of information on work and health characteristics at the occupational level, in one of Canada's largest working populations. The use of this data source to investigate relationships between shift work and depression still holds relevance today, since the hypothesized underlying relationships are temporally consistent. Furthermore, the annual prevalence of major depression in Canadians remained steady between 2002 and 2012 (4.8% and 4.7%, respectively) (201) and an increasing proportion of employed Canadians (approximately 33%) worked some form of shift work in 2011 (11), compared to 28% in 2005 (2). This study's findings are also relevant elsewhere, given the elevated prevalence of depression and other measures of psychological morbidity observed in nursing populations outside of Canada, such as the USA and the UK (269,270).

3.5 Conclusions

As with other areas of shift work epidemiology, the quality of evidence linking shift work to depression is challenged by the use of coarse exposure assignment that does not sufficiently consider characteristics of shift work exposure with impacts on the outcome. The high precision shift work schedule exposure indicator assigned in this study (an improvement over many others used in studies of shift workers) incorporated considerations of both shift timing and intensity of shift rotations. This definition reduced within-group heterogeneity compared to the low- and moderate-precision indicators, and produced the strongest associations with depression in this sample of nurses. This study's findings support the need to use precise and conceptually driven exposure assignment in future studies of shift work and health, to correctly assess and identify exposure-response relationships within individual studies, and to appropriately target health interventions to reduce the personal and economic burden associated with shift work. Further research into the effects of shift rotation frequency on depression is also recommended.

Chapter 4: Assessing determinants of workplace-level shift work policies and practices: An employer survey in British Columbia, Canada

4.1 Introduction

Shift worker health is influenced by a variety of workplace, social, and personal factors (4,19). The complexities of shift work exposure and its various pathways to health outcomes point to the need for a comprehensive systems approach (e.g., targeting workplace, social, and personal factors) to mitigate its impacts (271).

Interventions to reduce the health and social burden associated with shift work should include multiple leverage points, such as workplace, social, and individual factors (129). Although the scheduling preferences and needs of shift workers may vary considerably across a number of personal and social factors that should be considered for prevention purposes (71), workplace-level interventions (defined as "planned, behavioural, theory-based actions that aim to improve employee health and well-being through changing the way work is designed, organized, and managed" (272)) are a vital means for health promotion at a population level (273). For instance, workplace-level interventions can be broadly applied, and do not rely on the participation of a small number of highly motivated individuals (129).

A number of modifiable workplace policies and practices - concerning shift work scheduling (60,61), light-at-night levels (155), and health promotion to target individual-level factors (62) - have been linked to positive health outcomes in shift workers, and are potential targets for further research and intervention.

One aspect of shift work scheduling policy and practice that has received considerable attention is the optimal length of a shift to maintain health (4), with some viewing long work hours as being most problematic to shift workers (1). While there is no consensus definition for this concept within a work shift (i.e., extended or "long" hours) (1), the effects of altering shift duration as a health intervention are frequently assessed by comparing outcomes in 8-hour versus 10- or 12-hour shifts. Evidence to support the benefits and drawbacks of typical 8-hour shifts versus long duration shifts is mixed (71) and partly depends on the outcome in question. For example, long duration shifts appear to confer greater worker satisfaction (274), while short duration shifts tend to optimize workplace safety outcomes and provide more time for work recovery between shifts (4,275).

As described in section 1.1.2.3 of this dissertation, exposure to light-at-night has been linked to disrupted circadian rhythmicity in various physiological processes (e.g., melatonin suppression and sleep disruption) (32,46) that may impact on shift worker performance and health outcomes. Lighting in workspaces serves a variety of purposes, such as a sense of personal security, detection of hazards, and support of visual performance (67,68), and lighting levels can be expected to vary across different work environments and tasks (68,69). However, despite light-at-night's ubiquity and its potential effects on performance and health, workplace-level policies and practices that determine worker exposure levels are not well described in the literature.

Individual-level workplace policies and practices include employer provision of shift work education materials and training to employees, such as training sessions for shift workers and their partners, individual counselling, or written materials (71). Such resources may cover a number of individual-level behavioural strategies to cope with shift work, including topics such as alertness at work, safe driving, and healthy sleep, eating, physical activity, and family/social relationships (62,71). Though not a substitute for scheduling and work environment interventions, shift work education may be incorporated into a comprehensive systems approach to mitigating the impacts of shift work (271).

4.1.1 Study rationale and objective

Although a singular "silver bullet" solution is unlikely, interventions that target modifiable workplace policies and practices (such as scheduling, lighting, and health promotion) are important aspects of comprehensive approaches to promote workplace health and safety (276). However, little empirical information exists to describe the determinants and prevalence of modifiable shift work policies and practices in workplaces.

Such knowledge could be used to identify research targets and inform interventions to mitigate negative health outcomes in shift workers. This is particularly relevant for future workplace-based research into shift work and health, where random assignment of worker clusters (e.g., units within a hospital) to an intervention has been recommended as a more practical alternative to the randomization of individual workers (62). The objective of this exploratory study was to identify determinants of workplace-level shift work policies and practices with potential impacts on health across a range of industry sectors, in a survey of employers reliant on shift work.

4.2 Methods

This interview-administered study focused on organizations that employ shift workers across a range of industries within the province of British Columbia, Canada. In 2014, British Columbia had a workforce of 2.3 million (277), approximately one third of whom were shift workers (278).

4.2.1 Survey development

Survey items concerning shift work schedule characteristics and the provision of shift work education materials/training to assist workers with shift work adaptation, performance, and safety were drawn from a previous study of shift work practices conducted in British Columbia (279). Workplace-level factors hypothesized to affect the use of shift work schedules, nighttime lighting policies, and educational resources were identified following a review of literature that described various aspects of work organization and shift system design (e.g., (25,59)) and consultation with colleagues in relevant research fields (e.g. epidemiology, circadian science, and human resources).

The survey also contained questions about every shift schedule (defined as a generally consistent pattern of shifts worked by an employee that differed from another employee's pattern of shifts) used within a given workplace. Shift schedules were characterized by: shift coverage period (e.g., day, evening, or night), shift duration in hours, specific start and end times of shifts, regularity (e.g., always work nights versus rotating between days and nights), type of shift rotation if present (e.g., switching from days to nights versus nights to days), and typical number of days' rest between shifts.

An initial version of the survey was piloted with human resources and labour relations managers employed in the entertainment and manufacturing sectors to ensure relevance and clarity of wording; feedback from this process informed improvements for the final survey version (Appendix C.1).

4.2.2 Recruitment and data collection

An existing database of organizations employing shift workers in British Columbia was used for recruitment. This database, developed in 2003 for the purpose of other shift work research (279), contained 178 organizations that represented a range of industry sectors and employer sizes in the province

Between September 2014 and July 2015, contact by phone and/or email was attempted with all 178 organizations in the database. An interview was conducted with a representative employed at every consenting organization (each organization was counted as one study participant). In situations where the listed contact individual had retired, changed positions, or left the organization, an alternate representative with appropriate knowledge of work scheduling within the organization was sought for interview. This was determined by asking "who at your organization is most knowledgeable about work scheduling?" The majority of interviews were conducted with representatives in management, n = 55; followed by human resources, n = 25; and company leadership (e.g., president, vice-president, or owner), n = 8.

In addition to the shift work employer database, additional participants in healthcare, construction, and retail were recruited to ensure adequate representation of all British Columbia shift work sectors where shift work is common, as identified in the Canadian Census (278). This recruitment was conducted via contacts known to the study team.

Interviews were conducted by four study team members who had received survey administration training by A. Hall to increase consistency in recording and reporting for this study. Other measures to promote inter-interviewer and temporal consistency included interviewer prompts embedded within the survey, an interviewer guide with survey terminology and procedural reminders, and group meetings conducted throughout the study to discuss survey progress and interview techniques.

4.2.3 Study variables

Hypothesized determinants of workplace-level shift work policies and practices were organized into two groups. Group 1 represented more fixed characteristics (less variable over time): industry group, organization size, workplace size, and workforce unionization. Group 2 represented more flexible characteristics (more variable over time) that were reported to influence shift work scheduling within the organization: economic factors (e.g., production or business demand), client service or care needs, site maintenance needs (e.g., stocking, cleaning, or equipment maintenance), temporal factors (e.g., changes across seasons, weeks, or days), previous accidents or incidents that occurred during non-daytime hours, concern for employee health (mental, physical, injuries, or other), and employee preference concerning their schedule.

Three discrete workplace-level shift work policies or practices with potential impacts on health were investigated:

A. *Use of long (12 hours or more) versus short (less than 12 hours) duration shifts,* derived from the shift start and end times reported by each organization

B. *Provision of shift work education materials/training to employees*, obtained from the question: "Does your organization provide employees with any training or educational materials designed to help them adapt to working shifts? (e.g., safety meeting, workshop, manual, or information pamphlet)"

C. *Existence of nighttime lighting policies in the workplace*, obtained from the question: "Do(es) you(r organization) have workplace policies regarding lighting levels at night (that is, official requirements to lower or brighten lighting at certain times?)"

4.2.4 Statistical analyses

Analyses were performed using SAS software, version 9.4. (182) There were no missing values for any of the variables assessed. To assess the influence of selected determinants on workplace-level shift work practices, logistic models were constructed for each outcome:

A. Organization uses "long" duration shifts of 12 hours or more (Yes/No)

B. Organization provides shift work education materials/training to employees (Yes/No)

C. Organization has nighttime lighting policies in the workplace (Yes/No)

The objective of this exploratory study was to generate evidence to expand a limited body of evidence on shift work practices and policies and their determinants. Therefore, the modeling approach focused on choosing the strongest determinants of shift work practices from the survey data. For each outcome, automatic stepwise modeling was used to select determinants from Variable Group 1 first and then determinants from Variable Group 2, using a significance level cut-off of $p = 0.10$ for both entry and retention in the model. Retained determinant variables from Group 1 and Group 2 models were then combined and manual stepwise regression was conducted to develop a final logistic model for each outcome, using a significance level cut-off of $p = 0.10$. This level was chosen to ensure that other potentially informative variables (that did not reach "statistical significance" at the traditional $p = 0.05$ level cut-off) were reported.

4.3 Results

4.3.1 Descriptive summaries

Participating organizations were recruited from all major industry sectors in British Columbia where shift work was used. For industries employing larger proportions of shift workers, multiple organizations were recruited to promote adequate representation of each sector.

Out of the original shift work database (n = 178 organizations), 13 had merged into 6; 18 had gone out of business; 37 could not be reached by the study team; and 33 were unwilling to participate. This produced a database response rate of 54% (83 out of 153 organizations still in business). Two participating organizations no longer had hours of operation meeting the study definition of "shift work", and were therefore excluded. Targeted recruitment (response rate of 100%) produced an additional 7 participating organizations in the healthcare, construction, and retail sectors. This resulted in a final study sample of 88 participating organizations, representing 50,000 workers (out of which 30,700 were shift workers) in the province of British Columbia. A summary of study recruitment is provided in Appendix C.

Grouping by the North American Industry Classification System (NAICS) 2012 two-digit level industry sectors, the largest numbers of participating organizations were located in Manufacturing (n = 16), Transportation and Warehousing (n = 14), Public Administration (n = 9), Wholesale and Retail Trade (n = 8), Healthcare (n = 8), and Accommodation and Food Services (n = 7). To ensure adequate cell sizes for analytic purposes, participants were grouped into three industry categories (shown in Table 4.1).

Additional participating organization characteristics are presented in Table 4.1. Nearly half of all organizations (49%, n = 43) reported that concern for employee health influenced shift work scheduling at their organization; however only one third of organizations (33%, n = 29) provided employees with education materials/training to assist with adaptation to shift work. One third of organizations (34%, n = 30) reported official workplace policies regarding nighttime lighting levels, and one third of organizations (35%, n = 31) used long duration shifts of 12 hours or more. Responses to these questions were not mutually exclusive; 6 participating organizations reported "Yes" for all three outcomes, and 29 reported "No" for all three outcomes. The most common overlap was observed in participating organizations that reported "Yes" for both long duration shifts and provision of shift work education materials/training (14%, n = 12).

Table 4.1: Characteristics of participating organizations: British Columbia employer survey, 2014-2015

		Long duration shifts (12 hours or more) used[1]: Yes	Shift work education materials/training provided[1]: Yes	Nighttime lighting policies in workplace[1]: Yes
	n (% of all participants)	n (% of all participants)	n (% of all participants)	n (% of all participants)
	88 (100)	31 (35)	29 (33)	30 (34)
Variable Group 1: "Fixed" characteristics				
	n (% of all participants)	n (% of variable category)	n (% of variable category)	n (% of variable category)
Industry group				
Government *(municipal, provincial, federal)*	25 (28)	11 (44)	10 (40)	10 (40)
Private *(primary industry & manufacturing)*	23 (26)	12 (52)	9 (39)	5 (22)
Private *(service & accommodation)*	40 (46)	8 (20)	10 (25)	15 (38)
Organization size				
<1000 employees	43 (49)	9 (21)	11 (26)	12 (28)
1000+ employees	45 (51)	22 (49)	18 (40)	18 (40)
Workplace size				
<99 employees	42 (48)	5 (12)	8 (19)	13 (31)
100+ employees	46 (52)	26 (57)	21 (46)	17 (37)
Workforce unionized				
Yes	56 (64)	23 (41)	23 (41)	20 (36)
No	32 (36)	8 (25)	6 (19)	10 (31)
Variable Group 2: "Flexible" characteristics (reported to influence shift work scheduling)				
	n (% of all participants)	n (% of variable category)	n (% of variable category)	n (% of variable category)
Economic factors (e.g., production or business demand)				
Yes	64 (73)	20 (31)	22 (34)	22 (34)
No	24 (27)	11 (46)	7 (29)	8 (33)
Client service or care needs				
Yes	56 (64)	18 (32)	18 (32)	24 (43)
No	32 (36)	13 (41)	11 (34)	6 (19)
Site maintenance needs (e.g., stocking, cleaning, or equipment maintenance)				

	n (% of all participants)	n (% of variable category)	n (% of variable category)	n (% of variable category)
Yes	29 (33)	11 (38)	10 (34)	14 (48)
No	59 (67)	20 (34)	19 (32)	16 (27)
Temporal factors (seasonal work)				
Yes	49 (56)	11 (22)	11 (22)	21 (43)
No	39 (44)	20 (51)	18 (46)	9 (23)
Temporal factors (days of the work week)				
Yes	39 (44)	12 (31)	14 (36)	15 (38)
No	49 (56)	19 (39)	15 (31)	15 (31)
Temporal factors (hours of the work day)				
Yes	42 (48)	11 (26)	17 (40)	16 (38)
No	46 (52)	20 (43)	12 (26)	14 (30)
Collective agreements				
Yes	44 (50)	19 (43)	20 (45)	18 (41)
No	44 (50)	12 (27)	9 (20)	12 (27)
Previous accidents or incidents that occurred during non-daytime hours				
Yes	16 (18)	8 (50)	8 (50)	10 (63)
No	72 (82)	23 (32)	21 (29)	20 (28)
Concern for employee health (mental, physical, injuries, or other)				
Yes	43 (49)	19 (44)	19 (44)	17 (40)
No	45 (51)	12 (27)	10 (22)	13 (29)
Employee preference				
Yes	49 (56)	18 (37)	16 (33)	17 (35)
No	39 (44)	13 (33)	13 (33)	13 (33)

[1] *Outcomes are not mutually exclusive and therefore do not add to 100%*

4.3.1 Logistic regression

Associations between determinant variables and shift work outcomes are presented in Table 4.2 for the final multivariable logistic regression models. The odds ratio for long duration shifts was higher in organizations with larger workplaces, and in government organizations and private organizations in primary industry and manufacturing (relative to private organizations in service and accommodation industries). The odds ratio for providing shift work education materials/training was higher in organizations with larger workplaces, in organizations that reported no seasonal changes in shift work, and in organizations that reported shift work scheduling related to concerns about employee health. The odds ratio for having nighttime lighting policies in the workplace was higher in

Table 4.2: Final logistic models for associations between determinant variables and outcomes of (1) long duration shift use, (2) provision of shift work materials/training to employees, and (3) nighttime lighting policies in the workplace, British Columbia employer survey, 2014-2015

Organization uses long duration shifts (12 hours or more) (yes versus no)		
	OR	**95% CI**
Workplace size		
<99 employees	1.0	-
100+ employees	11.63	3.56 - 38.02
Industry group		
Private (service & accommodation)	1.0	-
Private (primary industry & manufacturing)	5.73	1.53 - 21.47
Government (municipal, provincial, federal)	4.14	1.15 - 14.93
Organization provides shift work education materials/training to employees (yes versus no)		
	OR	**95% CI**
Workplace size		
<99 employees	1.0	-
100+ employees	2.81	1.01 - 7.78
Shift work related to seasonal needs		
Yes	1.0	-
No	3.37	1.20 - 9.46
Shift work related to organizational concern for employee health (mental, physical, injuries, or other)		
Yes	3.33	1.18 - 9.38
No	1.0	-
Organization has nighttime lighting policies in the workplace (yes versus no)		
	OR	**95% CI**
Shift work related to previous accidents or incidents that occurred during non-daytime hours		
Yes	3.80	1.16 - 12.49
No	1.0	-
Shift work related to site maintenance needs		
Yes	2.48	0.92 - 6.68
No	1.0	-
Shift work related to client service or care needs		
Yes	2.74	0.93 - 8.08
No	1.0	-

OR = Odds Ratio; CI = Confidence Interval organizations that reported shift work scheduling related to previous non-daytime workplace accidents or incidents, in organizations that reported shift work scheduling related to maintenance activities, and in organizations that reported shift work scheduling related to client service or care needs.

4.4 Discussion

This study identified determinants of workplace-level shift work policies and practices among a sample of 88 employers in the Canadian province of British Columbia, representing over 30,000 shift workers. Over 400 distinct shift work schedules were reported (results not shown), providing yet another example of shift work's complexity. Larger workplace size was strongly associated with the outcomes of long duration shifts and the provision of education resources to shift workers, but not to the presence of nighttime lighting policies. Industry group was also strongly associated with long duration shifts, with government and private organizations in primary industry & manufacturing sectors more likely to use long duration shifts than private organizations in service & accommodation sectors. Factors related to shift work scheduling within an organization, including seasonal (temporary) work and concern for worker health, were strongly associated with employer provision of shift work education materials/training to employees. Other factors related to shift work scheduling, including previous workplace accidents and incidents occurring during non-day shifts, site maintenance needs, and client- or service-based needs, were associated with the presence of nighttime lighting policies in the workplace.

4.4.1 Long duration shifts

Approximately one third (35%, n = 31) of participating organizations in this study reported the use of long duration shifts (12 hours or more) in their workplaces, of which the majority (n = 29) were 12 hours. The odds ratio for long duration shifts was higher as a function of larger workplace size and type of industry sector, with government organizations and private organizations in primary industry and manufacturing more likely to use shifts with extended durations relative to private organizations in service and accommodation industries.

These findings agree with previously noted differences in shift work characteristics across industries. Split shifts, which are typically of shorter duration, are most common in retail trade, hospitality, and entertainment/recreation industries (4,280); all of which were categorized into this study's industry group of private organizations in service and accommodation. Employees in primary industry (such as mining operations) in British Columbia may perform many consecutive long duration shifts while working in remote areas. The use of long duration shifts may also arise from historical traditions of working patterns in some industries, such as in municipal protection services (included in this study), or in large employers that have been established for long periods.

Evidence and implications concerning the health effects of long shift durations is discussed further in Section 5.2.

4.4.2 Provision of shift work education materials/training to employees

In this study, only one third (33%, n = 29) of participating organizations reported the provision of education materials or training designed to assist with adaptation to shift work. This low proportion may indicate a lack of recognition regarding shift work's potential health impacts, or there may be insufficient expertise at the workplace level to obtain, evaluate, and distribute shift work education materials and training to employees in some instances.

Concerning the impacts of workplace size on shift work education or training, a body of research indicates that small workplaces have relatively greater difficulties controlling occupational health and safety risks (281–283) and may not always use information and supports when they are available, due to economic and cultural factors (282). Conversely, larger organizations tend to have greater access to worker health expertise (e.g., industrial hygienist on staff, health and safety committees) and economic resources to distribute educational resources. In the Canadian context, it has been suggested that occupational health and safety practices in small workplaces could be improved through the development of information systems that gather occupational health and safety data by workplace size; such information could then be used to inform the case for legislative and policy changes that incorporate small business considerations (283). Another study conducted in the Canadian province of Quebec found that the most common prevention activities in small firms were linked to production efficiency (284). This suggests that the integration of prevention into production activities (e.g., championing the business incentives of shift worker education and training) could be an effective strategy for shift workers in small workplaces.

Temporary shift work (defined in this study as differences in shift work scheduling across months or seasons) was reported by over 50% of organizations in industries such as Construction, Agriculture, and Accommodation and Food Services. This study's finding that organizations with seasonal (precariously employed) shift workers are less likely to provide shift work education is consistent with other research that suggests the transient nature of temporary workforces challenges the maintenance of workplace health programs, risk assessment, and injury/health surveillance (222). Temporary workers have also been noted to receive less training during paid working hours relative to permanent workers (254,285). The issue of how to support precariously employed workers has recently received greater attention in Canada (254). Recommendations focus on taking a broader view to workforce development, by creating government policies that are responsive to labour market needs yet also ensure access to training opportunities that support precariously employed workers and enable them to find more secure employment (254).

The finding that employer concern for health drives the provision of shift work education and training is somewhat intuitive. Out of the 29 participating organizations that provided shift work education and training to their employees, 13 reported concern about mental health, 12 about physical health, 9 about injuries, and 7 about "other" health concerns (6 of the 7 were fatigue-related). While this is interesting, the interview structure of this study cannot identify which specific health concerns led to the introduction of shift work education materials/training in participating organizations. However, taken together with findings on prior history of work-place injuries, the results suggest that general concern about shift worker health and safety may be a good lever for the implementation and provision of workplace-level shift work policies and resources.

There has been surprisingly little published research on the short- and long-term efficacy of shift work education programs. Where provided, the type and quality of shift work education materials and programs varies widely across organizations (279), and such information does not always reach its intended audience (159). Further research is needed to assess which types of training programs and materials are effective for enhancing tolerance to shift work, and to ensure that such interventions provide improvements to health and well-being without inducing further harm. This is particularly important given the complexities of individual factors (e.g., age, gender, genetics) and other mechanisms that may drive shift work's effects on health, such as sleep, social stress, lifestyle, and environmental factors (17,19,146). The need for input from shift workers themselves has also been identified as a future priority in this area, to ensure that working environment interventions to improve shift worker health actually reach their intended targets (159).

Government incentives to support the provision of education and training to shift workers could also serve as a lever to promote the broad reach of such individual-level interventions. A specific recommendation that could be applied to shift work education practices refers to an already established (and purportedly successful) model in the province of Quebec, where employee training is encouraged through a government tax incentive for employers, and a 1% payroll tax applied to employers who do not provide training (254). In turn, the planning and implementation of other workplace-level health interventions, such as a shift system change, would be supported by worker education and training, since information, communication, and worker participation have been identified as important elements in this process (71).

4.4.3 Nighttime lighting policies

Official nighttime lighting policies in the workplace were reported by 34% (n = 30) of participating organizations in this study. This suggests that considerations of shift worker health do not typically drive decisions concerning workplace lighting, although interpretations are limited by a lack of explicit detail on the policies themselves (for example, dimming versus brightening of lights at certain times).

The odds ratio for having nighttime lighting policies in the workplace was higher in organizations that reported shift work scheduling related to previous accidents or incidents during non-daytime hours, client service or care needs, and site maintenance activities. Specific motivating factors and circumstances for nighttime lighting policies were not assessed in this study, although determinants showing the strongest associations with light policies have face value. For example, client service/care needs and site maintenance activities are logical drivers of lighting use. Previous accidents/incidents in the workplace were also associated with nighttime lighting policies. Of the 30 participating organizations that reported nighttime light policies, 33% (n=10) reported that a previous nighttime incident had affected shift work scheduling practices in the organization. Of the 58 participating organizations that did not report nighttime light policies, 10% (n=6) reported that a previous nighttime incident had affected shift work scheduling practices in the organization. This suggests that previous nighttime incidents or accidents might serve as a lever or instigator for the implementation of best practices. For example, workplace incidents may prompt an occupational health and safety investigation or regulatory inspection activity that leads to change, particularly when penalties are applied (286).

Workplace-level interventions may be driven by a range of motivations other than concern for employee health, such as structural changes (downsizing or upsizing), or other business concerns (e.g., efficiency, productivity, cost) (287). This study cannot verify that concern about employee health was a major driver for nighttime lighting policies in the organizations that reported them. Of the 30 participating organizations that reported nighttime light policies, 57% (n = 17) reported that concern about employee health affected shift work scheduling within their organization, versus 45% (n = 26) of the 58 participating organizations that did not report nighttime light policies. In another survey question (results not shown), 14% (n = 12) of participating organizations did report providing bright lighting to enhance shift worker performance, alertness, safety, and well-being. These findings suggest that lighting policies may be driven somewhat by concern for worker safety and health, however "energy efficiency" and "cost savings" were mentioned by multiple participating organizations as the driving factors for nighttime lighting policies (results not shown). Therefore, future research that makes both health and economic arguments for workplace interventions could provide a good incentive for organizations to implement nighttime lighting policies with multiple benefits.

4.4.4 Strengths and limitations

This exploratory study of determinants of workplace-level shift work policies and practices used stepwise modeling to select the best combination of variables for each shift work outcome, before offering these variables jointly to build the final models. While the majority of determinant variables in the final models met the more traditional cut-off value of $p = 0.05$, a less restrictive cut-off value of $p = 0.10$ provided information on additional determinants of shift work practices (site maintenance needs and client service/care needs) that may be useful to consider in future research and intervention strategies. Although Type I error (the incorrect identification of an effect that is not truly present) is possible given the number of variables and models that were analyzed, the final workplace determinants have face validity to support their associations with assessed shift work outcomes.

The study results also included the 95% confidence intervals around the odds ratios to provide evidence of the precision around these estimates. The widths of these intervals reflect the study's small sample size and variability in reported shift work practices. Despite imprecision around the point estimates, the strength of associations and their consistency with other literature supports their validity.

The study's small sample size (n = 88) required the aggregation of some explanatory variables to increase cell sizes and stabilize regression estimates; this resulted in the masking of potentially valuable information at a finer level (e.g., industry type, workplace size). The small sample size also restricted the investigation of additional shift work practices with potential benefit to shift workers, such as flexible working time arrangements (61,63,288) and type of rotational shift work (60,62). For example, few participating organizations in this study reported worker self-scheduling (16%; n = 14) or backward rotations (2%; n = 2) (results not shown) precluding analyses of relationships between these variables and workplace-level determinants in this sample. The small numbers observed also suggest that employers in British Columbia may not commonly use such scheduling policies and practices.

The individuals interviewed on behalf of participating organizations were selected based on their familiarity with shift work scheduling at each organization. Due to differences in workplace size and employment position (scheduling versus management) interviewees may not have been equally familiar with “on the ground” practices within workplaces, and some misclassification may have occurred for both the determinant variables and outcome variables. Although not ideal, such misclassification would likely be non-differential, and therefore more likely to bias effect measures towards the null (not produce spurious effects). If social desirability bias affected the reporting of workplace concern about employee health, the association between this variable and the provision of shift work education materials/training to employees may have been overestimated. However, less than half (49%) of participating organizations indicated that concern for employee health influenced shift work practices within their organization, suggesting that this effect may be small.

This study included organizations from a range of industry sectors that were hypothesized to be a potential source of variability in shift work practices. Although a range of workplace sizes was also sought, the final study sample over-represents large workplaces (16% of participating organizations represented workplaces with more than 500 employees, versus the 8% provincial average) and under-represents small workplaces (9% of participating organizations represented workplaces with fewer than 20 employees, versus the 38% provincial average) (289). Since results may vary due to the resources available within workplaces of differing size, more research is needed to clarify determinants of shift work practices in smaller organizations that employ shift workers.

4.5 Conclusion

This study represents the first known analytic examination of determinants of workplace-level shift work policies and practices. Results point to high-level characteristics that may be used to guide interventions and research where they are most needed (or most likely to be effective) concerning shift work scheduling, light-at-night, and health promotion for shift workers. For example, industry sector and workplace size may be important considerations in research or interventions focused on shift duration. Workplace size, seasonal changes in shift work, and employer concern for worker health may be important considerations in research or interventions focused on individual-level health promotion. Previous workplace incidents occurring during non-day shifts, site maintenance needs, and client- or service-based needs may be important considerations in studies or interventions focused on nighttime lighting policies and practices in workplaces.

Chapter 5: Discussion

Shift work is a prevalent work arrangement in modern society that can disrupt workers' natural rhythms of biology and socialization. Although it may not fit into the traditional occupational hygiene paradigm, shift work appears to be an important causal factor for a number of health outcomes, and should assessed with the same rigour as other occupational hazards. In fact, greater rigour in exposure assessment may be warranted, since the composition and intensity of shift work exposures extend beyond traditional factors such as job title and workplace characteristics (290).

High quality workplace-based research is needed to assess shift work's effects on health, including intervention studies aimed at minimizing its impacts. However, a number of methodological issues in epidemiological studies of shift work have limited the development of evidence-based interventions and policies to support shift worker health. One major methodological challenge is that shift work represents a highly variable mixture of exposures that is difficult to study. This reality will endure for as long as shift work exists; in other words, indefinitely. Therefore, an important and relevant question for health researchers is: How can we do a better job of studying shift work, in order to develop stronger evidence and thus clearer guidance to reduce its negative impacts?

It has been proposed that the ability to cope with shift work relies on the mutually interactive domains of the circadian, sleep, and social/domestic systems (291). It is therefore interesting that much shift work research has assessed simple linear relationships, often focusing on biomedical models of disrupted sleep and circadian rhythms (i.e., the time-of-day effects of work schedule), while ignoring other pathways that may link shift work exposures to health (as described in section 1.1.2). Theoretical development and testing has not been a primary focus of shift work research (1). Attempts to develop more complex models that incorporate general stress concepts have been lauded for increasing diversity in shift work research, yet have also been criticized for their lack of clarity and utility as heuristic frameworks rather than descriptions of data (128). Therefore, as was recently emphasized elsewhere (292), opportunities exist to develop comprehensive shift work models that thoroughly and accurately characterize the strongest pathways (biological, social, and psychological) linking shift work with health.

Such work is needed in order to identify the strongest pathways (biological, social, and psychological) linking shift work with health. Various methods have been suggested for such refinements, including: 1) investigating research questions that arise from existing shift work models and using findings to clarify/diversify theory (e.g., incorporate stress research on individual coping mechanisms); 2) developing narrower theories that specify the shift work features that are related to health outcomes, and in which organizational circumstances; 3) developing symptom-focused theories to explain the etiology of individual health problems among shift workers, by describing specific physiological and/or psychological mechanisms (128).

Regardless of the method pursued, it is clear that future research focused on the effects of shift work on health should take a comprehensive approach to assessing the individual in addition to the combined effects of shift scheduling, work demands, sleep, and the psychosocial context at work and home. In these studies, multiple outcome measures should be included on circadian adjustment, sleep, and recovery, corresponding to the hypothesized underlying health mechanisms. The contribution of non-work activities and stressors should also be assessed to understand how time off and demands outside of work may contribute to circadian entrainment, sleep, and recovery (292). Researchers interested in a wider conceptualization of upstream factors relating to work organization and shift work may choose to integrate broader social determinants of health into such models.

The insufficiency of simple approaches to exposure assessment is not a new concept in occupational epidemiology (293), and the need for more sophisticated and standardized exposure assessment in epidemiological studies of shift work has increasingly been realized in recent years (21,23,80). To move this science forward, we must progress beyond the status quo use of crude exposure assessment. Relevant shift work characteristics and their variability should be considered at every step of the epidemiological process (i.e., during planning, data collection, analysis, and interpretation) to meaningfully describe exposures and reduce the potential for exposure misclassification, measurement error, and bias. These considerations require the collection of detailed exposure *measurements* (e.g., light-at-night exposure data, details of a work schedule, history of exposure) to examine which fundamental aspects of exposure are important to assess underlying relationships (290). Such data is needed to inform the *assignment* of exposure indices that are specific and relevant to the health outcome(s) of interest (or, in cases where a priori mechanisms are not well understood, to compare different exposure indices and metrics in the analysis) (293). Data that describe *determinants* of workplace-level shift work policies and practices are also needed to inform targeted research and interventions aimed at mitigating population-level health risks, based on strong evidence of associations where they exist.

5.1 Summary of studies, methodological considerations, and recommendations for future research

This dissertation presents a series of three exposure assessment studies focused on the *measurement*, *assignment*, and *determinants* of shift work exposure in epidemiological research. These studies provide new information that can be applied to strengthen future studies, including: quantitative data that describe light-at-night exposure levels and their variability in shift workers, and an examination of exposure metrics (in Chapter 2), evidence to support the assignment of specific exposure indices that are based upon clearly formulated hypotheses of exposure-response relationships (in Chapter 3), and new insights into determinants of workplace-level shift work policies and practices (in Chapter 4).

In Chapter 2, light-at-night exposure levels in shift workers were documented as an initial step in the *measurement* of exposure levels and variability. Personal full-shift light-at-night exposure measurements (n = 152) were collected from 102 shift workers in emergency health services (paramedics, dispatchers) and healthcare industries (nurses, unit clerks, security guards, and support, pharmacy, and laboratory staff). Descriptive and variance component analyses were conducted for the 23:00-05:00 period to characterize exposures using multiple metrics of potential biological relevance. The highest exposures were observed in medical laboratory workers in healthcare while the lowest exposures were observed in dispatch officers in emergency services. Between-group variance was large relative to between-worker and within-worker variance for all exposure groupings and metrics, with variance increasing as grouping precision increased. All exposure metrics were moderately to highly correlated.

This study provides new information about light-at-night exposure levels and variability in emergency services and healthcare workers, using multiple exposure indices and exposure metrics that were based on a current understanding of human physiologic responses to light. Findings suggest that light-at-night exposures may be more temporally consistent than other traditional workplace exposures, and that a number of exposure metrics and high-level grouping schemes may be useful to characterize and describe these exposures. While the methods used to assess variability in this study have previously been used to assess occupational hazards such as chemical agents (162), dusts (294), and musculoskeletal strain (168), they are new to the field of shift work. Measurement collection and characterization of light-at-night exposures in shift workers could provide significant improvements over the standard use of “shift work” or “shift work involving nights” as a proxy for light-at-night exposure in studies of shift work and health.

New findings from this study are informative, but they should not be regarded as prescriptive for all shift workers in healthcare or emergency services. Light-at-night exposures occurring outside of the assessed sample could be different with respect to their intensity or temporal variability. As described elsewhere (134), the collection of quantitative exposure measurements prior to an epidemiological study can be a useful way to maximize it impacts. Such data can be used to inform considerations of exposure variability in a target research population, such as sampling strategies that increase study efficiency, as well as the assignment of grouping schemes that maximize accuracy and exposure contrast for analyses. For these reasons, light-at-night exposure should be measured and assessed prior to any large epidemiological study seeking to investigate its effects on health.

Research into light-at-night exposure and health is a new and evolving scientific area, with many questions still to be answered about which exposure characteristics (e.g., duration, timing, illumination levels, spectral characteristics) carry the strongest impacts on a variety of health outcomes. The assessment of photopic illuminance levels and variability in Chapter 2 allows for comparisons with most prior epidemiological studies of nighttime light exposure on health. Photopic illuminance is an appropriate exposure measure for studies of short-term alertness (172,196,197) in shift workers, and is also a relevant measure to assess melatonin suppression in humans (295,296). However, collecting data on light-at-night as it affects the visual system may not be sufficient to fully characterize circadian disruption in shift workers (181), since light exposure on the retina affects the human visual and circadian systems differently (199). For example, visual reaction time is in the order of milliseconds and can be stimulated by light ranging from starlight (~0.0001 lux) to midday sun on a clear day (~100,000 lux) (199), whereas the circadian system requires sustained light stimulation with a threshold of ~30 lux (saturation occurring at ~1000 lux) (199). Light-at-night's suppressive effect on melatonin also depends on the type and timing of light exposure, with greater impacts observed with longer exposure to high intensity light in the short wavelength ("blue") range during periods of biological darkness (70). Therefore, while Chapter 2 provides useful new information on shift workers' light-at-night exposure levels and variability during the biological period of darkness, there are opportunities to expand upon this assessment in future research by using measures of the circadian system's sensitivity, threshold, and saturation.

An accumulation of strong evidence in this area could be used in future to inform lighting standards that consider the health impacts of lighting. To date, authorities such as the Illuminating Engineering Society and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have only incorporated considerations of the human visual system (e.g., needs for safety and task performance), but not considerations of neuroscience (e.g., nocturnal melatonin response, circadian stimuli) into regulated lighting standards (67). It has been suggested that various lighting benefits be incorporated into a broader definition for use in lighting standards (67); to do so, collaboration between specialists in neuroscience research and lighting applications is necessary to develop practical, evidence-based lighting changes that both improve human health and performance, and increase energy efficiency.

In Chapter 3, the implications of exposure *assignment* precision on the nature and strength of shift work's relationship with depression was investigated using a large, nationally representative survey of Canadian nurses. High, moderate, and low precision shift work exposure indicator groups were used. The high precision exposure indicator group considered both shift timing and frequency of rotation, while the moderate precision group considered only shift timing, and the low precision group considered only the presence or absence of shift work. In the analyses, the point estimates of associations observed in the high precision shift work schedule model (incorporating considerations of rotation frequency) were stronger than those of the medium and low precision models, where weak associations were observed for all schedule categories.

The assignment of exposure indicators is an important scientific consideration in epidemiological studies. A poorly chosen indicator of exposure can result in misclassification of subjects' exposures, thereby introducing measurement error and distorting relationships (166). Unfortunately, these important concepts are frequently ignored in epidemiological studies of shift work, where the assignment of coarse exposure indicators has been the norm. In Chapter 3, neither the low nor the moderate precision exposure definition produced strong associations between shift schedule and depression. However, the high precision exposure definition (that included considerations of shift timing and rotation frequency) found positive associations between high frequency shift rotations and depression, and negative associations between low frequency shift rotations and depression, relative to regular day workers. These results demonstrate that in this study population, exposure assignment considering only shift work absence/presence, or considering only shift timing and not rotation frequency, would have produced exposure misclassification and a conclusion of "no effect" for depression related to shift work. Findings from this study therefore reinforce the need to: 1) collect sufficiently detailed exposure information from research participants, and 2) apply this information to assign specific exposure indices, in order to minimize the potential for measurement error due to exposure misclassification.

This task of detailed exposure data collection and assignment should be informed by considerations of causal mechanisms that are outcome specific, since different types of shift work may produce varying levels of risk across outcomes (23). For instance, an appropriate shift work exposure definition for long-latency diseases such as cancer (e.g., focused on history of exposure, number of nights worked, etc. (21)) may not be appropriate for assessing mental health effects in the short-term, where other shift work characteristics (such as quick returns between shifts, or short notice of work schedule) may constitute equal or greater problems for shift workers (220).

Future research that collects and incorporates detailed, hypothesis-driven characteristics into the assignment of exposures would help to identify the most accurate and precise exposure indices to assess health risks within studies. The consistent assignment of specific and biologically based exposure indicators for health outcomes would also permit better comparisons across studies of shift work. This point was demonstrated in a recent study that used administrative data on individual working hours to examine how eight different exposure definitions impacted calculations of the number of night shifts worked (297). The investigators found marked differences in the number of nights worked when comparing night shift defined by specified periods of night time (e.g., working at least 3 hours between 24:00 and 05:00) versus night shift defined by start and end time (e.g., beginning after 19:00 and ending before 09:00). Such differences would affect the proportions of workers categorized as exposed or unexposed to shift work, with potential impacts on both the estimation of risk within studies, as well as the comparability of results between studies.

In Chapter 4, potential *determinants* of workplace-level shift work policies and practices were described. Data on shift work scheduling, provision of shift work education materials/training to employees, and nighttime lighting policies in the workplace were collected during phone interviews with employers across the Canadian province of British Columbia. The sample included 88 participating organizations, representing 30,700 shift workers across industries common to most western countries, such as manufacturing, service, retail, and healthcare. Long duration (12+ hour) shifts, provision of shift work education materials/training to employees, and nighttime lighting policies were each reported by approximately one third of participating organizations. The use of long duration shifts was more likely in larger workplaces, and varied by industry. Employer provision of shift work education materials/training was more likely in larger workplaces, in organizations where shift work scheduling was related to concern for shift worker health, and in organizations without seasonal changes in shift work. Workplace nighttime lighting policies were more likely in organizations where shift work scheduling was related to previous workplace accidents or incidents occurring during non-daytime hours, site maintenance needs, and client service or care needs.

Shift work is a highly variable exposure with a number of workplace, social, and individual factors that may influence its effects on health, and there is no blanket solution to address its negative consequences. As described in Chapter 4 however, workplace-level interventions are an important means to promote population health. Reviews on the topic of shift work (62) and organizational and stress intervention (273) have emphasized the need for more intervention research conducted at the workplace level.

Despite their perceived importance to research and public health, workplace interventions have been characterized as time consuming, expensive, and difficult to describe, control, and evaluate (273). This could explain why few intervention studies that target modifiable risk factors for health outcomes in shift workers, such as workplace policies and practices, have been conducted outside of experimental or simulated settings (62,156). The resulting dearth of information is generally problematic, but especially so for long-term health promotion in shift workers, since interventions to prevent chronic diseases are even more complex to conduct (148).

Workplace-based intervention research is important to identify what works for whom, and in what circumstances, by studying the context of an intervention (e.g., in what conditions are an intervention effective?) as well its mechanisms (what makes an intervention work?) (272). As one author aptly states: "the alert researcher should always look for windows of opportunity to perform intervention research" (273). A better understanding of the links between high-level workplace characteristics and shift work policies and practices is therefore useful to support progress in this area.

Results from Chapter 4 point to determinants of workplace-level shift work policies and practices that could serve as targets for future epidemiological research and interventions. These include industry sector and workplace size (for shift duration), workplace size, seasonal changes in shift work, and employer concern for worker health (for individual-level health promotion), and previous workplace accidents or incidents occurring during non-daytime hours, site maintenance needs, and client service or care needs (for nighttime lighting policies).

It is surprising that little other information is available to describe high-level determinants of shift work practices and policies. There are many opportunities for future studies to assess the validity of Chapter 4's findings and to expand this knowledge base, such as through similar investigations that assess larger samples or different jurisdictions. Industry-based studies would provide a means to probe reasons behind the relationships observed in Chapter 4, such as motivating factors for the use of certain types of shift work schedules, the existence of light-at-night policies, and the provision of worker education. In addition to informing targets for future research and prevention, such information could also provide a clearer picture of the barriers and facilitators to conducting shift work-related research and translating the evidence obtained into best practices within workplaces (272). Time requirements for recruiting and interviewing participants in future studies is an important consideration; for example, recruitment, interview, and follow up activities for each participant (organization) in Chapter 4 required approximately 6 hours.

5.2 Conflicting imperatives in translating shift work and health research

While eliminating shift work might be the best way to minimize circadian disruption and negative health impacts, this would clearly ignore the requirements of work and life in modern society (32). Instead, practical questions for worker health relate to questions such as: How can nighttime lighting be applied for maximal benefit? Which work schedules cause minimal impact? How can information about health maintenance and self-protection be meaningfully communicated to workplaces and individuals? High quality epidemiological studies are needed to answer these questions, and to inform policies and workplace interventions that will effectively support the health of shift workers. Such evidence might also help to address the challenge of conflicting imperatives (23) that emerge due to the range of health effects arising from a myriad of shift work exposures.

One clear example of conflicting imperatives arising in this dissertation relates to the development of recommendations for "healthy" nighttime lighting in workplaces. Exposure to light-at-night is a strongly hypothesized mechanism linking shift work to cancer (3) and as such, measures to minimize its effects on natural sleep-wake rhythms are recommended (161), particularly since total adaptation to night work is unlikely in most circumstances (1). Conversely, exposure to bright light has a direct alerting effect (172,296,298) that has been found to confer acute safety benefits by increasing alertness and enhancing performance during work at night (196,197,299,300). At first glance, this conflict suggests an impossible situation concerning the short-term protection of worker safety versus the long-term maintenance of health. However, recent scientific findings have indicated that longer wavelength "red" light might provide alerting benefits without suppressing melatonin in shift workers (161,301). This points to future research opportunities into "healthy" nighttime lighting technologies that allow individuals to see and remain alert while concurrently minimizing melatonin suppression and disruption to circadian rhythms and sleep.

A second example of conflicting imperatives arising in this dissertation relates to developing practical advice for "optimal" shift duration, due to conflicting evidence for the benefits of using short versus long duration shifts (62,71). A number of studies have demonstrated positive effects of 12-hour shifts in nurses (302) and other shift workers (61), perhaps due to related benefits such as longer periods of time off from work, more time for family and friends, greater satisfaction with working hours (303) and work-life balance (274), and improved sleep compared to an 8-hour shift schedule (62). Beneficial effects of longer shifts (12+ hours versus 8 hours or less) on depressive outcomes are also identified in Chapter 3 of this dissertation. Other research indicates that 8-hour shifts are associated with less fatigue and sleepiness during the work period (303) and decreased risk of workplace incidents and errors compared to 12-hour shifts (275,304), with a cumulative increasing risk of incidents in shifts exceeding 8 hours (305). In industrial environments, shorter shifts can be advantageous to reduce the potential for prolonged toxic exposures and increase time off between shifts to clear chemicals with longer half-lives (303). Shorter workdays (of 6 hours) have also been associated with decreased risk for musculoskeletal pain relative to work shifts of 7 hours or more (306).

Inconsistent findings regarding the impact of long duration shifts on health may be due to differences in the occupations or job tasks studied (e.g., workload, monotonous tasks), workplace factors (e.g., rest break policies, staff resources, distribution of work shifts and rest days), or other more general factors (e.g., commuting time) (4). While these inconsistencies challenge the specification of universally applicable recommendations for optimal shift duration, some of the conceptual conflicts could be resolved with more methodologically rigorous intervention studies in the future (61). Furthermore, future evidence-based recommendations should consider the reasons for long duration shifts being favoured in large workplaces and in certain types of industries, as described in Chapter 4.

These examples demonstrate some of the challenges facing the translation of research findings into practice. It is interesting to note that very few shift worker intervention designs have assessed a combination of approaches to promote health (62), when this could be a more effective strategy to address the complexities of shift work exposure and its various health effect modifiers. Future health studies and interventions, particularly those that examine a broad spectrum of actions (to address multiple exposures and modifiers) and take a long-term perspective (to demonstrate long-lasting effects) (148), require strong research methods in order to produce accurate results that can be effectively interpreted and applied. Therefore, it is certain that the need for strong exposure assessment in intervention-focused epidemiological studies will persist.

5.3 Summary

This PhD dissertation aimed to provide new information on the *measurement, assignment*, and *determinants* of shift work exposure in epidemiological studies of shift work, to address current evidence gaps and inform future methods in this area. Chapter 2 was conducted to measure personal light-at-night exposure levels in emergency services and healthcare workers in British Columbia, as an initial step to characterizing occupational exposure levels, variability, and metrics. It was found that exposures varied across occupations and work environments yet were generally stable over time in this population, suggesting that high-level grouping schemes may be appropriate to identify and describe light-at-night exposures in future research. The exposure metrics assessed were moderately to highly correlated; therefore multiple metrics may be useful in future epidemiological studies, depending upon the conceptual nature of the research question. Chapter 3 was conducted to examine how exposure assignment precision would affect observed relationships between shift work schedule and depression in a large sample of Canadian nurses. The strongest associations with depression were observed with the high-precision exposure indicator group that measured both timing of work and frequency of shift changes. This finding supports the need for detailed and hypothesis-based exposure assignment in future studies, and provides new epidemiological evidence of shift work's effects on mental health. Finally, Chapter 4 was conducted to describe and assess determinants of workplace-level shift work policies and practices thought to affect health across a range of industry sectors in British Columbia, Canada. Results indicate that industry sector, workplace size, seasonal work, past workplace incidents occurring during non-daytime hours, the nature of work tasks, and concern for worker safety and health are associated with shift work policies and practices; such factors should be considered in future epidemiological research and interventions.

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Appendix A

Supporting documentation for Chapter 2 (Personal light-at-night exposures and components of variability in two industry sectors where shift work is common)

A.1 Additional detail on study recruitment

Study approval to contact workers and conduct on-site measurements was obtained from the Workplace Health Division of British Columbia's Provincial Health Services Authority, and from upper management representing both the British Columbia provincial emergency medical services and the British Columbia Women's Hospital. Study approvals were then obtained from subsequent levels of management for each occupational group within emergency services (paramedics and dispatch workers) and the Women's Hospital (nursing, security, patient care aides, unit clerks, and laboratory staff).

Worker recruitment was conducted in a manner suitable to each worksite. For instance, paramedics at participating ambulance stations were informed in advance about the study via emailed study introduction letters and notices posted at their worksite; workers that were present on four pre-determined sampling dates were then invited to participate ad hoc. For nurses, a study notice was sent to all Women's Hospital nursing staff in a weekly emailed newsletter, and notices were posted in staff rest areas to invite nurses to contact the research team to participate.

Appendix B

Supporting documentation for Chapter 3 (Examining the impacts of exposure assignment in a study of shift work and depression among nurses)

B.1 Depression scoring in the National Survey of the Work and Health of Nurses

The following text in Section B.1 was taken directly from Shields and Wilkins' summary of findings from the 2005 National Survey of the Work and Health of Nurses (1), p. 107-109:

Using the methodology of Kessler et al. (2), history of a major depressive episode (MDE) was measured using a subset of questions from the Composite International Diagnostic Interview. These questions cover a cluster of symptoms for a depressive disorder, which are listed in the Diagnostic and Statistical Manual of Mental Disorders (DSM-III-R) (3).

Two screening questions were used for the depression module. The first was,

- During the past 12 months, was there ever a time when you felt sad, blue, or depressed for two weeks or more in a row?

Respondents who replied "yes" to this question were instructed to think about the 2-week period during the past 12 months when these feeling were the worst, in reference to the following questions:

1. "During that time how long did these feelings usually last . . .all day long, most of the day, about half of the day, or less than half the day?" (Respondents who replied "about half of the day" or "less than half the day" were not asked questions 2 to 11).
2. "How often did you feel this way during those two weeks . . . every day, almost every day, or less often?" (Respondents who replied "less often" were not asked questions 3 to 11.)
3. "During those two weeks did you lose interest in most things?" (yes / no)
4. "Did you feel tired out or low on energy all of the time?" (yes / no)
5. "Did you gain weight, lose weight, or stay about the same?" ("gained weight," "lost weight," "stayed about the same," "was on a diet.")

6. “About how much did you gain/lose?” (not asked if the respondent was on a diet)
7. “Did you have more trouble falling asleep than you usually do?” (yes / no)
8. “How often did that happen . . . every night, nearly every night, or less often?”
9. “Did you have a lot more trouble concentrating than usual?” (yes / no)
10. “At these times, people sometimes feel down on themselves, no good, or worthless. Did you feel this way?” (yes / no)
11. “Did you think a lot about death; either your own, someone else’s, or death in general?” (yes / no).

The second screening question for the depression module, “During the past 12 months, was there ever a time lasting two weeks or more when you lost interest in most things like hobbies, work, or activities that usually give you pleasure?” was asked of respondents who replied “no” to the first screening question or were “skipped out” of the subsequent questions based on their response to item 1 or 2.

Respondents who replied “yes” to the second screening question were asked the same follow-up questions (1 to 11) but with the difference that they were instructed to “think about the 2-week period during the past 12 months when you had the most complete loss of interest in things.” As well, the wording for item 1 was revised to “During that two-week period, how long did the loss of interest usually last?”, and item 3 was not asked.

To derive a depression score, all respondents were assigned an initial value of 0. For each of the eight criteria listed below that was met, a value of 1 was added to the initial value; thus the total score could range from 0 to 8.

- a response of “yes” to either screening question
- a response of “yes” to item 3
- a response of “yes” to item 4
- a change of weight of at least 10 pounds (4.5 kilograms), indicated in item 6
- a response of “every night” or “nearly every night” to item 8
- a response of “yes” to item 9
- a response of “yes” to item 10

- a response of “yes” to item 11

The scores were transformed into a probability estimate of the occurrence of an MDE. For the analysis, if the estimate was 0.9 or more, that is, 90% likelihood of an MDE, the respondent was considered to have experienced a depressive episode in the previous 12 months. To obtain a probability of 0.9, respondents had to score 5 or more.

References

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Appendix C

Supporting documentation for Chapter 4 (Assessing determinants of workplace-level shift work policies and practices: An employer survey in British Columbia, Canada)

C.1 Copy of questionnaire used

SFU

CIRCADIAN RHYTHMS LABORATORY
SIMON FRASER UNIVERSITY

CONTACT INFORMATION
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Canada

Full Interview

2014 Survey of Shiftwork Practices in British Columbia

Type of industry: ....

Organization ID: ....

INTERVIEWER: Thank-you for agreeing to participate in this survey. It consists of three major sections: **Section 1** will ask for general information about your organization and shiftwork practices, factors that may influence shiftwork, and changes to shiftwork over time. **Section 2** will ask specific questions about each shiftwork schedule used at your organization. Finally, **Section 3** will ask questions about any employee training or resources that your organization may offer to shiftworkers. Before we begin, do you have any questions for me?

Section 1: General Information

INTERVIEWER: First, I'm going to ask some general questions about your organization.

1. **How many people** does your organization employ (total)? …………

1b. **How many** people does your unit (AKA, department, area of the company) employ? …………

2. **How many** of the people employed by your organization are **shiftworkers**? As a reminder, **we define 'shiftwork'** as any work schedule in which one half or more of the work hours fall before 0700 h or after 1700 h. This includes permanent evening and night shifts, rotating shifts (switching from day, evening or night work hours at daily, weekly, monthly or irregular intervals), and split shifts (2 work periods per day), and some cases of extended duty hours (work periods of 12 h or longer).

   Number: …………

3. **How many** of your organization's **shiftworkers** are employed on a **full-time** basis?

   Number: ……… N/A (no full-time shiftworkers): ……… D/K: ………

4. **How many** of your organization's **shiftworkers** are employed on a **part-time** basis?

   Number: ……… N/A (no part-time shiftworkers): ……… D/K: ………

5. **How many** of your organization's **shiftworkers** are employed on a **casual** or **auxiliary** basis:

   Number: ……… N/A (no casual/auxiliary shiftworkers): ……… D/K: ………

6. **How many** of your organization's **shiftworkers** are employed on a **seasonal** basis:

7. Number: ……… N/A (no seasonal shiftworkers): ……… D/K: ………

8. Are your organization's employees **unionized**? Yes ………… No …………

   If no, proceed to question 9.

   If yes, approximately what percentage of employees are unionized? ………..%

   If yes, how many collective agreements cover unionized employees within your organization? …………

9. What are your organization's typical **hours of operation** (when are employees present?) ………………..

10. **How many different shift schedules** are used at your organization?

   A "shift schedule" can be defined as a generally consistent pattern of shifts worked by an employee that differs in any way from another employee's pattern of shifts. **Examples of differences in shift schedule include:**

   - Shift coverage period *(day, evening, or night)*
   - Shift start time *(starting at 4am vs. 8am)*
   - Permanency of shift *(always work nights vs. rotating between days and nights)*
   - Type of shift rotation *(days to nights vs. nights to days)*
   - Shift duration *(8hr shift vs. 12 hr shift)*
   - Typical amount of rest between shifts *(N-N-R-R-N-N vs. N-N-N-N-R-R-R-R-N-N-N-N)*

   Note: We define individuals performing irregular work with no consistent pattern as ONE shift schedule category.

   Number of schedules: ………

   Comments: ………

   ……

   I'll ask specific questions about each of these shift schedules a bit later, in Section 2.

INTERVIEWER: Now I'm going to ask about **factors that might influence shiftwork scheduling** at your organization.

11. Do **economic factors** (such as production or business demand) influence shiftwork scheduling at your organization?

   Yes …… No …… N/A …… D/K ……

   If yes, please describe: ……………………………………………………………………………………………

   ……

12. Do **client service or care** needs influence shiftwork scheduling at your organization?

   Yes …… No …… N/A …… D/K ……

   If yes, please describe: ……………………………………………………………………………………………

   ……

13. Do **site maintenance needs** (such as stocking, cleaning, or equipment maintenance) influence shiftwork scheduling at your organization?

Yes …… No …… N/A …… D/K ……

If yes, please describe: …………………………………………………………………………………………

………

13. Do any of the following **temporal factors** influence shiftwork scheduling at your organization?

a. Seasonal (certain months or seasons) Yes …… No …… N/A …… D/K ……
b. Weekly (certain days of the week) Yes …… No …… N/A …… D/K ……
c. Daily (certain hours of the day) Yes …… No …… N/A …… D/K ……

If yes, please describe: …………………………………………………………………………………………

………

14. Do **collective agreements** influence shiftwork scheduling at your organization?

Yes …… No …… N/A …… D/K ……

If yes, please describe: …………………………………………………………………………………………

………

15. Have **previous accidents or incidents** that occurred during non-daytime hours influenced shiftwork scheduling at your organization?

Yes …… No …… N/A …… D/K ……

If yes, please describe: …………………………………………………………………………………………

………

16. Does concern for **employee health** influence shiftwork scheduling at your organization?

Yes …… No …… N/A …… D/K ……

If no, proceed to question 17.

If yes, what are your organization's specific concerns about shiftworker health? (*Check all that apply):*

a. Injuries ……
b. Mental health ……
c. Physical health ……
d. Other ……

Comments: ……………………………………………………………………………………………

………

17. Does **employee preference** influence shiftwork scheduling at your organization?

Yes …… No …… N/A …… D/K ……

If yes, please describe:

………

………

18. Does **anything else** influence shiftwork scheduling at your organization?

Yes …… No …… N/A …… D/K ……

If yes, please describe:

………

………

INTERVIEWER: Now I'm going to ask some questions about historical changes to shiftwork scheduling at your organization.

19. In the past 10 years, has your organization **increased** the number of employees performing shiftwork?

Yes ……. No ……. N/A …… D/K ……

If yes, please describe the reason(s) for this increase:

………

………

20. In the past 10 years, has your organization **decreased** the number of employees performing shiftwork?

Yes ……. No ……. N/A …… D/K ……

If yes, please describe the reason(s) for this decrease:

………

………

21. In the past 10 years, has your organization **increased** time off between shifts (as in, added more hours or days between shifts)?

Yes ……. No ……. N/A …… D/K ……

If yes, please describe the reason(s) for this increase:

………

………

22. In the past 10 years, has your organization **decreased** time off between shifts (as in, reduced the hours or days between shifts)?

Yes ……. No ……. N/A …… D/K ……

If yes, please describe the reason(s) for this increase:

…………………………………………………………………………………………………

…………………………………………………………………………………………………

23. In the past 10 years, has your organization changed the direction of shift rotation from **Forward** (for example, rotating from days to evenings or nights) **to Backward** (for example, rotating from nights to evenings or days)?

Yes ……. No ……. N/A …… D/K ……

If yes, please describe the reason(s) for this change:

…………………………………………………………………………………………………

…………………………………………………………………………………………………

24. In the past 10 years, has your organization changed the direction of shift rotation from **Backward** (for example, rotating from nights to evenings or days) **to Forward** (for example, rotating from days to evenings or nights)

Yes ……. No ……. N/A …… D/K ……

If yes, please describe the reason(s) for this change:

…………………………………………………………………………………………………

…………………………………………………………………………………………………

25. In the past 10 years, has your organization changed its policy to allow **shift trading** between employees?

Yes ……. No change (it's not allowed)……. No change (it was always allowed) …… D/K ……

If yes, please describe the reason(s) for this change:

…………………………………………………………………………………………………

…………………………………………………………………………………………………

26. In the past 10 years, has your organization changed its policy to allow worker **self-scheduling?**

Yes ……. No, it is not allowed……. No, it was always allowed …… D/K ……

If yes, please describe the reason(s) for this change:

…………………………………………………………………………………………………

…………………………………………………………………………………………………

27. In the past 10 years, have there been any **other** changes to your organization's shiftwork scheduling?

    If yes, please describe:

    ……………………………………………………………………………………………………

    ……………………………………………………………………………………………………

28. If in the past 10 years there were **no changes** to your organization's shiftwork scheduling, please indicate the reason(s). (*Check all that apply*)

    a. This shift schedule has always been used …………
    b. Employees prefer this schedule …………
    c. Management prefers this schedule …………
    d. Employee union(s) prefer this schedule …………
    e. Don't know …………
    f. Other *(please describe)* ……………………………………………………………

INTERVIEWER: Now I'm going to ask some questions about **nighttime lighting** use in your organization.

29. Do you have workplace **policies** regarding **lighting levels at night** (that is, official requirements to lower or brighten lighting at certain times?)

    Yes ……. No ……. D/K …….

    If yes, please describe: ……………………………………………………………………………

    ……………………………………………………………………………………………………

30. Are you aware of **employee practices** regarding **lighting levels at night?** (e.g., employees prefer to lower or brighten lighting at certain times?)

    Yes ……. No ……. D/K …….

    If yes, please describe: ……………………………………………………………………………

    ……………………………………………………………………………………………………

Section 2: Details of each shift schedule *(Interviewer should repeat questions 31 to 41 for each shift schedule identified in Question 9)*

INTERVIEWER: You previously identified ___ distinct shift schedule types used by your organization. In this section I will ask questions about each one of these shift schedules.

Shift schedule # ________

31. Is this shift schedule: *(check only one)*
    a. Rotating, regular (usually a fixed pattern) ……….
    b. Irregular (no pre-set pattern for individuals) ……….
    c. Permanent (day, morning, evening, or night) ……….

32. What are the **start** and **end** times of each shift within this schedule? *(please use 24-hr clock)*

Shift	Start-times	End-times
Morning		
Day		
Evening		
Night		

33. Please provide a brief summary of the **job descriptions** using this shift schedule. Note that we are interested in the TOTAL number of employees working this schedule (not just the number of employees on a given shift).

(INTERVIEWER NOTE: If there are more than 4 job titles working this shift schedule, please add on back of page)

Job Title 1…………………………………………………………………………………………………

Number of employees …………

Gender breakdown: Men …………% Women …………%

Workplace area…………………………………………………………………………………………………

Main tasks…………………………………………………………………………………………………

Job Title 2…………………………………………………………………………………………………

Number of employees …………

Gender breakdown: Men …………% Women …………%

Workplace area…………………………………………………………………………………………………

Main tasks…………………………………………………………………………………………………

Job Title 3……………………………………………………………………………………………………

Number of employees …………

Gender breakdown: Men …………% Women …………%

Workplace area……………………………………………………………………………………………

Main tasks………………………………………………………………………………………………

Job Title 4……………………………………………………………………………………………………

Number of employees …………

Gender breakdown: Men …………% Women …………%

Workplace area……………………………………………………………………………………………

Main tasks………………………………………………………………………………………………

34. **How long** has this shift schedule been used?

………………………………………………………………………………………… *Don't know* ……

35. **Who designed** this shift schedule? Please indicate all that apply from the following list:

a. Management …………
b. Union …………
c. Non-union employee rep(s) …………
d. Outside consultant ………… f. Other (indicate who) …………
e. Don't know …………

36. How is the **roster/schedule filled**? Please indicate all that apply from the following list:

a. Shifts are set by management ………….
b. Shifts are set by management, employees call in availability or can decline ………….
c. Shifts are determined (primarily) by seniority ………….
d. Employees indicate availability; management then sets schedule ………….
e. Other *(describe)* ………………………………………………………………………… …….
f. Don't know ………….

37. Typically, how many shifts are worked by an employee in this schedule each week? ………… month? …………

38. What is the maximum number of consecutive shifts allowable without a day off? …………

39. For this shift schedule,

a. What is the typical sequence of shifts (e.g., 2 days, 2 nights, 4 off)? *If the shiftwork pattern is very complex), use chart below to show a complete cycle of this shift schedule including rest days: M (Morning), D (Day), E (Evening or afternoon), N (Night), and R (Rest).*

……

	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Week 1							
Week 2							
Week 3							
Week 4							
Week 5							
Week 6							
Week 7							
Week 8							

b. **(For rotating shifts only),** what is the **direction** of shift rotation? *(Choose only one):*

Forwards (e.g., day to evening to night) ………

Backwards (e.g., night to evening to day) ………

40. a. Is there any opportunity for **over-time**? Yes …… No ……

If no, proceed to 41.

If yes,

b. Within a given pay period, approximately **how many over-time** hours are there? ………………

c. Which shift is **most likely** to be worked by someone on overtime? *(choose one):*

Day ……. Morning ……… Evening ……… Night ……… Don't know ………

41. Is there **anything else** about this shift schedule that you can tell me (…that you think I should know?)

……

……

……

INTERVIEWER NOTE: After the participant has provided information for all shift schedules in Section 2, please check that all shiftworking occupation(s) in their organization have been included:

INTERVIEWER: "Are there any other job descriptions performing shiftwork at your organization, that haven't been mentioned?"

Section 3: Employee Training and Resources

INTERVIEWER: Now I'm going to ask some questions about training and programs that your organization may provide to shiftworkers.

42. a. Does your organization provide employees with any **training** or **educational materials** designed to help them adapt to working shifts?

Yes …… No …… D/K ……

If no, proceed to question 44.

If yes, what kind of training or educational materials does your organization provide? (*Check all that apply*):

b. **'Safety meeting'** or **workshop** given by:

i. Health and safety officer ……..

ii. Human resources/employee relations ……..

iii. Outside 'expert' consultant ……..

c. Manual or information pamphlet ……..

d. Other *(please describe)*: ………………………………………

43. **When** is this training and/or educational material given to employees?

a. Safety meetings or workshops	When hired ……..	Yearly ……..	Occasionally ………	D/K ………
b. Pamphlets	When hired………	Yearly ……..	Occasionally ………	D/K ………

44. Does your organization offer any **special programs or facilities** designed to enhance shiftworker performance, alertness, safety, well-being, etc.?

a. Overnight food service	Yes ……	No ……	D/K ……
b. Bright lighting (beyond that for normal use)	Yes ……	No ……	D/K ……
c. Exercise facility	Yes ……	No ……	D/K ……
d. Napping facility	Yes ……	No ……	D/K ……
e. Car or van pooling	Yes ……	No ……	D/K ……
f. Childcare assistance	Yes ……	No ……	D/K ……

g. Other (please describe):……………………………………………………………

……………………………………………………………………………………

INTERVIEWER: These are all of the questions that I have regarding your organization's shift-work practices. Do you have any questions or comments for me?

……………………………………………………………………………………

……………………………………………………………………………………

Section 4: Contact Information: (detach page and file separately)

INTERVIEWER: Before we finish, I would like to ensure that the contact information that I have for your organization is accurate.

Name of organization: ____

Contact Person: ____

Position: ____

Phone: ____

Email: ____

Address: ____

____

____

____

INTERVIEWER: Are you willing to be contacted by our study team members for future shiftwork research?

Yes …… No ……

INTERVIEWER: "We're finished. Thank-you very much for your time and assistance. If you have any questions about the research, please don't hesitate to contact Andrea Smit at 778-782-6613 (asmit@sfu.ca) or Amy Hall at 778-887-2317 (amyhall@mail.ubc.ca).

C.2 Summary of study recruitment

Industry Description (2-digit code, NAICS 2012)	% Shift workers by BC industry[1]	Recruitment of organizations via shift work database						Targeted recruit-ment (n)	Study total
		Total in database (n)	Consent (n)	Refusal (n)	Out of business (n)	Non-response (n)	Response rate (%)		
Agriculture, forestry, fishing, hunting (11)	3.4	11	5	0	1	5	50	0	**5**
Mining, quarrying, oil and gas extraction (21)		5	2	0	1	2	50	0	**2**
Utilities (22)	0.1	2	2	0	0	0	100	0	**2**
Construction (23)	2.0	3	1	2	0	0	33	1	**2**
Manufacturing (31-33)	13.8	38	16	13	4	5	47	0	**16**
Wholesale trade (41)	23.8	5	4	0	1	0	100	0	**4**
Retail trade (44-45)		5	3	2	0	0	60	1	**4**
Transportation and warehousing (48-49)	7.7	28	15	7	0	6	54	0	**14**[2]
Information and cultural industries (51)	3.0	9	2	1	2	4	29	0	**2**
Arts, entertainment and recreation (71)		10	5	0	2	3	63	0	**5**
Finance and insurance (52)	1.2	1	0	0	1	0	0	0	**0**
Real estate and rental and leasing (53)		0	0	0	0	0	N/A	0	**0**
Professional, scientific and technical services (54)	0.3	4	0	0	0	4	0	0	**0**
Management of companies and enterprises (55)	4.6	0	0	0	0	0	N/A	0	**0**
Administrative and support, waste management and remediation services (56)		8	5	1	1	1	71	0	**4**[2]
Educational services (61)	1.0	2	2	0	0	0	100	0	**2**
Health care and social assistance	15.5	5	5	0	0	0	100	3	**8**

(62)									
Accommodation and food services (72)	17.8	11	6	2	2	1	67	1	**7**
Other services (except public administration) (81)	2.8	3	2	1	0	0	67	0	**2**
Public administration (91)	3.2	21	8	4	3	6	44	1	**9**
TOTAL	100	171	83	33	18	37	54	7	**88**

NAICS = North American Industry Classification System

BC = British Columbia, Canada

[1] Reference: Statistics Canada. 2006 Census of Population. Ottawa, Canada; 2006.

[2] One organization did not meet the study definition of "shift work" and was excluded