TITLE: Assessment of exposure to shiftwork mechanisms in the general population: *the development of a new job-exposure matrix*

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What this paper adds

- Shiftwork has the potential to affect the health of workers via a number of biological mechanisms.
- Previous job-exposure matrices (JEMs) for assessing exposure to shiftwork focus only on exposure to night work or rotating shifts.
- This paper describes the development of a JEM for assessing exposure to several variables that reflect biologically plausible mechanisms for the effect of shiftwork on health.
- This JEM may provide an alternative method of exposure assessment in the absence of detailed job history and exposure data in general population studies.

ABSTRACT

Objective: To develop a job-exposure matrix (JEM) that estimates exposure to eight variables representing different aspects of shiftwork among female workers.

Methods: Occupational history and shiftwork exposure data were obtained from a population-based breast cancer case-control study. Exposure to light at night, phase shift, sleep disturbances, poor diet, lack of physical activity, lack of vitamin D, graveyard and early morning shifts, was calculated by occupational code. Three threshold values based on the frequency of exposure were considered (10%, 30% and 50%) for use as cut-offs in determining exposure for each occupational code. JEM-based exposure classification was compared to that from the OccIDEAS application (job-specific questionnaires and assessment by rules) by assessing the effect on the odds ratio (OR) for phase shift and breast cancer. Using data from the Australian Workplace Exposure Study, the specificity and sensitivity of the threshold values were calculated for each exposure variable.

Results: 127 of 413 occupational codes involved exposure to one or more shiftwork variables. Occupations with the highest probability of exposure shiftwork included nurses and midwives. Using the 30% threshold, the OR for the association between phase shift exposure and breast cancer was decreased and no longer statistically significant (OR=1.14, 95%CI 0.92-1.42). The 30% cut-off point demonstrated best specificity and sensitivity, although results varied between exposure variables.

Conclusions: This JEM provides a set of indicators reflecting biologically plausible mechanisms for the potential impact of shiftwork on health and may provide an alternative method of exposure assessment in the absence of detailed job history and exposure data.

INTRODUCTION

Shiftwork generally refers to the organisation of working hours such that different individuals work in succession, allowing work to continue beyond the typical eight hour day, and up to 24 hours.[1] Shift types typically include morning, afternoon, evening, and night, and can be further defined according to the worker's schedule of shifts - either the same shift all the time (permanent) or rotating in a clockwise/anticlockwise fashion.[2] Shiftwork is relatively common in developed countries. For example, among female workers, the prevalence of shiftwork was 17.2% in the European Union in 2005, 12.4% in the USA in 2004,[3]and 14% in Australia in 2009.[2] Australian industries with the highest proportion of females engaged in shiftwork were *Health Care and Social Assistance* and *Accommodation and Food Services* (both 32%), followed by *Arts and recreation services (24%)*.[2]

There has been interest in the adverse health effects associated with shiftwork particularly, the impact of night and rotating shiftwork on circadian rhythm, which is the 24 hour biological cycle that regulates sleep and wakefulness in humans, in synchrony with environmental stimuli such as light/dark, activity, and food intake.[4] Disruption of circadian rhythms can result in phase shift, which occurs when peripheral biological activities, such as digestion, become unsynchronised with the central sleep/wake cycle. Phase shift also alters metabolic activity and hormone secretion, which may contribute to long-term impaired metabolic health.[5]

Shiftwork related light exposure at night may also alter the secretion of the hormone melatonin, which is predominantly secreted by the pineal gland and is involved in the regulation of several physiological processes.[6] Under normal sleep/wake conditions, melatonin secretion is highest at night time. When exposure to light at night occurs, for example during night shifts, melatonin secretion can be reduced or shifted in timing.[7] Melatonin receptors are found in parts of the central nervous system and in peripheral organ systems including the female reproductive system. Alterations in endogenous melatonin production and receptor expression have been implicated in a number of diseases including certain cancers, coronary artery disease and Alzheimer's disease.[8] Of note, a meta-analysis of 10 studies found an increased risk of breast cancer among female shift workers, with a dose-response relationship with duration of shift work.[9] Elevated risk of ovarian cancer has also been found among women working rotating shifts.[10]

These shiftwork mechanisms have also been shown to affect aspects of female reproductive health. Altered menstrual cycle length and cycle irregularity have been reported among nurses who work rotating shifts,[11] and regular night shift work has been associated with increased risk of endometriosis.[12] Permant night shift work has been associated with an increased risk of spontaneous abortion among nurses and other occupations.[13, 14]

Other mechanisms that could contribute to adverse health effects among shift workers include disruptions to the quantity and quality of sleep, which have been associated with impaired immune function and metabolism and may lead to fatigue, with the potential for increased risk of workplace accidents and injury.[15, 16] There are also concerns that permanent night shift workers are at risk of vitamin D deficiency due to lower exposure to sunlight.[17] Shift workers are also reported to have relatively poor diets, be less physically active, have a higher body mass index, and be more likely to smoke and consume alcohol at harmful levels.[18]

However, it is important to consider the opportunity for self-selection for shiftwork amongst those with greater physiological tolerance, or amongst those with psychological states which are better suited the work pattern. Either may induce a form of selection bias, or ‘reverse causation’.

Shiftwork exposure can be ascertained via observation or surveying of workers, or via expert assessments. However, these methods usually require direct access to workers and may not be feasible for very large samples; therefore a job-exposure matrix (JEM) may be useful to impute exposures. A JEM is a cross-classification of occupational titles or codes and exposures,[19] often using data from exposure studies, expert assessments, biological measurements, or environmental monitoring. A JEM may be constructed for a specific industry or for use among the general population, and depending on its structure may provide estimates of the probability, frequency and/or intensity of exposure for each occupational title.

JEMs are often applied because of their ease of use and cost effectiveness, particularly in population-based studies, where information on occupational history is generally less detailed or when the size of the study makes other methods of exposure assessment less feasible.[20] Use of a JEM also allows standardized exposure assessment and reduces reporting bias, which may occur when the quality of the self-reported job histories and exposure information varies among participants.[21]

Assessment of shiftwork exposure in epidemiological studies is complicated by differences in the definitions of shiftwork, night shifts and rotating shifts applied across countries, industries and companies.[22] This has led to a range of metrics being used to capture the prevalence, duration and frequency of shiftwork schedules. Furthermore, while circadian disruption has been identified as a key mechanism for the detrimental health effects of shiftwork, particularly in relation to cancer, a clear definition of circadian disruption is yet to be established.[23]

Several JEMs exist for classifying shiftwork exposure among women.[24-26] The majority of these JEMs are industry-specific and focus only on exposure to night shift (yes or no), rather than the factors that potentially cause health effects. A mechanistic approach to shiftwork exposures on a biological basis can help to overcome differences in the definition of shiftwork and individual variation in ability to cope with shiftwork.[22] In light of the challenges in assessing shiftwork exposure, this paper presents a step towards the creation of JEMs with improved validity for linking occupations with shiftwork exposure among the female population. Our paper describes the development of a JEM in the general female population for assessing exposure to several variables that reflect biologically plausible mechanisms for the health effects of shift work.

METHODS

Source of exposure data

The exposure data used to construct the JEM was obtained from the Breast Cancer, Employment and Environment Study (BCEES).[22] This population-based case-control study recruited women aged 18-80 years. Cases were women who were first diagnosed with invasive breast cancer between May 2009 and January 2011, and were identified from the Western Australian (WA) Cancer Registry. Age-matched controls were randomly selected from the WA electoral roll. Data collection for BCEES involved a mailed questionnaire followed by a telephone interview to assess occupational exposures. The questionnaire collected information relating to demographics, reproductive history, and lifestyle factors, as well as details on all jobs held for at least six months over the woman's working life. Data from 1,785 controls were used to construct the JEM in this study.

Assessment of shiftwork exposures with OccIDEAS

Participants who reported in their questionnaire that they worked shifts or had any job that was likely to involve shiftwork went on to complete a structured telephone interview containing a job-specific module. Participant responses were recorded in OccIDEAS, an online application which manages the interview process and occupational exposure assessment.[27] The interview questions included the type of roster (regular, varied, on call), whether they worked between the hours of midnight and 5am (graveyard shift), and whether they worked a shift that started between 5am and 7am (early morning shift). For jobs that involved more than one consecutive graveyard shift, further questions were asked to assess shiftwork exposures based on an *a priori* framework that was established to enable the assessment of potential health effects of shiftwork using biologically plausible mechanisms.[28] These questions related to exposure to light at night, phase shift, sleep disturbance, poor diet, lack of physical activity, and lack of vitamin D. These six mechanistic variables, as well as graveyard and early morning shifts, formed the exposure variables for the JEM.

The use of alcohol to help sleep was also assessed; however it was omitted from the JEM as only 0.2% of participants reported exposure.

Using an inbuilt set of exposure rules, OccIDEAS provided automatic assessments of the probability of exposure to light at night, sleep disruption, poor diet, lack of physical activity, and lack of vitamin D for each of the jobs reported by the women interviewed. For each of these variables, only participants with probable exposure were considered exposed in this study. Exposure to phase shift was determined by manual review of the descriptions of shift schedules. The expert reviewers involved in this process were blinded to case-control status. The criteria used to establish probable exposure to each of the six mechanistic variables is outlined below.

Exposure to light at night was assessed by asking about the brightness of the light in the participant's normal working area during night shifts. Probable exposure was assigned for women exposed to bright or medium light in working areas and/or light in their bedroom when trying to sleep.

The phase shift variable was designed to identify patterns of shift work that produced desyncronisation of central and peripheral biological rhythms.BLASK 2011 It was assessed by determining how many consecutive night shifts were worked, and the direction of rotating shifts, that is, backwards (night-afternoon-morning) or forwards (night-morning –afternoon). Probable exposure was assigned to women who worked two or more nights of forward rotation or three or more nights of backward rotation consecutively. These definitions were based on evidence, albeit mainly from animal studies, which show that the central cycle starts to adjust after several days, with adjustment being quicker during forward rotation. Haus and Smolensky 2013

Sleep disturbances were assessed by asking about the amount of sleep (hours) obtained between consecutive night shifts, the quality of sleep (extremely well to extremely bad), difficulties in falling and/or staying asleep, the use of medication to help sleep and light and noise in the bedroom when sleeping. Women who experienced decreases in both quantity and quality were classified as having probable exposure to sleep disturbances.

Participants assessed the quality of their diet while on night shifts using a four-point scale ranging from very healthy (lots of vegetables and wholegrain cereals, fruit and some protein), to very unhealthy (mostly fatty and sweet foods). Participants whose diet was rated anything other than very healthy were considered exposed.

Physical activity was assessed by asking how many times per week the participant engaged in at least 20 minutes of vigorous exercise and at least 20 minutes of moderate exercise when working night shifts. Participants who vigorously less than three times per week, or moderately less than five times per week were considered exposed.

Finally, vitamin D was assessed by asking about the amount of time spent outdoors between two consecutive night shifts. Probable exposure to lack of vitamin D was assigned to those who spent less than one hour outside.).

Coding of occupational history data

Job title, main duties and industry were collected as part of each BCEES participant's occupational history. This information was used to classify each job according to the International Standard Classification of Occupation 1968 (ISCO-68).[29] The coder (RF) was blind to the respondent's shiftwork exposure and disease status. Where there were difficulties in allocating a code, discussions were held between the authors to reach an agreement.

Statistical analyses

To create the JEM, the proportion of BCEES workers who were probably exposed to each of the shiftwork variables (according to OccIDEAS) was used to produce an estimate of the prevalence of exposure for each occupational code. Three threshold values for exposure were considered: 10%, 30% and 50%. These values represent cut-offs for assigning exposure to a particular occupational code. For example, using the 30% cut point, a specific occupation would be classified as exposed to light at night if at least 30% of workers in that occupational code had been assigned exposure to light at night. The JEM was then reapplied to the BCEES occupational data to assess the effect on the risk estimate for phase shift when using the JEM for exposure classification compared to the original individual-level exposure assignments. This analysis was limited to the phase shift variable, as this was the only statistically significant result observed in the BCEES analysis of shiftwork exposures and breast cancer.[22] Odds ratios (OR) and 95% confidence intervals (CI) were estimated using logistic regression models, adjusted for age group.

In the absence of a gold standard for occupational exposure to shiftwork, we compared the JEM with the exposures assigned by OccIDEAS to individuals from a separate data set, the Australian Work Exposure Study (AWES).[30] AWES was a nation-wide cross-sectional telephone survey investigating the prevalence of current occupational exposure to 38 carcinogens, including shiftwork variables. Data collection for this study was carried out in 2011-2012, on a random sample of the population, reflecting the approximate distribution of the Australian work force by state and territory. Data were collected from 5,023 males and females aged between 18 and 65 who were currently in paid employment. The OccIDEAS application was used for data collection and exposure assessment (including shiftwork factors) in this study.[30]

Assessments of shiftwork exposure for the female AWES participants were made by applying the JEM to the job titles (coded to ISCO68). These exposure estimates were compared with those produced at an individual level by OccIDEAS based on the job-specific modules completed during the AWES data collection. Exposure prevalence was compared for the eight shiftwork variables described above. The assessments of exposure to these shiftwork variables by the JEM were evaluated by calculating sensitivity and specificity, in comparison with the OccIDEAS assignment of each job. This was done for each of the three cut-off points for the JEM. Sensitivity and specificity were calculated using the Stata user-written command 'diagt'.[31] Occupation codes that appeared in the AWES data but not BCEES were excluded from this analysis.

All data manipulation and statistical analysis was performed using Stata version 12 (StataCorp, College Station, TX, USA).

RESULTS

Of the 413 occupational codes present in the BCEES population, 127 involved exposure to at least one of the eight shiftwork variables. The highest prevalence of shiftwork exposure was found among occupations in ISCO68 Major Group 0/1: Professional, technical and related workers. The five-digit occupational codes within this group with the highest prevalence of exposure included specialised nurses and professional and auxiliary nurses and midwives. Relatively high prevalence of exposure was reported among some occupations in Major Group 5: Service workers, including nursing aides, and also in the supplementary major group containing armed forces personnel (Table 1).

TABLE 1: Occupational codes with at least 10 workers in which the prevalence of exposure to one or more of the shiftwork variables was 20% or more in a female study population (N=1 785).

ISCO-68 Occupation Code	**Count**	**Probability of exposure**							
Major Group 0/1 Professional, technical and related workers	**(N)**	**LN**	**PS**	**SD**	**PD**	**PA**	**VD**	**GY**	**EM**
0-14.90 Other physical science technicians	18	0.167	0.222	0.111	0.222	0.222	0.111	0.111	0.333
0-61.05 General physician	15	0.067	0.067	0.067	0.000	0.000	0.000	0.467	0.000
0-71.10 Professional nurse (general)	465	0.542	0.504	0.222	0.497	0.417	0.260	0.637	0.159
0-71.20 Specialised nurse	16	0.750	0.625	0.188	0.750	0.563	0.375	0.813	0.313
0-72.10 Auxiliary nurse	223	0.592	0.610	0.224	0.574	0.475	0.350	0.659	0.251
0-73.10 Professional midwife	98	0.806	0.786	0.429	0.765	0.541	0.449	0.959	0.316
0-74.10 Auxiliary midwife	19	0.789	0.789	0.263	0.789	0.526	0.263	0.842	0.158
0-76.20 Physiotherapist	13	0.231	0.154	0.154	0.231	0.077	0.000	0.231	0.000
0-77.10 Medical x-ray technician	19	0.316	0.105	0.053	0.211	0.211	0.211	0.579	0.158
Major Group 3: Clerical and related workers	**(N)**	**LN**	**PS**	**SD**	**PD**	**PA**	**VD**	**GY**	**EM**
3-80.20 Telephone switchboard operator	67	0.015	0.015	0.030	0.000	0.015	0.000	0.015	0.224
3-80.90 Other telephone and telegraph operators	13	0.231	0.154	0.231	0.231	0.154	0.077	0.231	0.077
3-94.90 Other receptionists and travel agency clerks	10	0.100	0.100	0.000	0.100	0.000	0.100	0.200	0.200
Major Group 5: Service workers	**(N)**	**LN**	**PS**	**SD**	**PD**	**PA**	**VD**	**GY**	**EM**
5-10.20 Working proprietor (hotel and restaurant)	12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250
5-10.50 Working proprietor (café, bar, and snack bar)	29	0.103	0.103	0.034	0.103	0.034	0.034	0.172	0.310
5-31.20 Head cook	13	0.077	0.077	0.000	0.077	0.000	0.000	0.077	0.538

5-31.30 Cook, except private service	49	0.020	0.020	0.000	0.020	0.020	0.020	0.082	0.286
5-99.40 Nursing aid	310	0.290	0.274	0.103	0.235	0.235	0.097	0.303	0.161
Major Group 7/8/9: Production and related workers, transport operators and labourers	**(N)**	**LN**	**PS**	**SD**	**PD**	**PA**	**VD**	**GY**	**EM**
9-85.40 Motor bus driver	10	0.100	0.100	0.000	0.100	0.100	0.100	0.100	0.200
9-85.50 Lorry and van driver (local transport)	29	0.034	0.069	0.034	0.034	0.034	0.069	0.103	0.310
Supplementary major groups	**(N)**	**LN**	**PS**	**SD**	**PD**	**PA**	**VD**	**GY**	**EM**
Armed forces	17	0.412	0.235	0.176	0.294	0.235	0.176	0.529	0.176

LN: Light at night, PS: Phase shift, SD: Sleep disturbances, PD: Poor diet, PA: Lack of physical activity, VD: Lack of vitamin D, GY: Graveyard shift, EM: Early morning shift.

In BCEES, the original OR for phase shift exposure and breast cancer using the OccIDEAS exposure classification was 1.21 (95% CI 1.01 – 1.47).[22] Based on the JEM (30% cut-off point), the OR was reduced in magnitude and no longer statistically significant (OR = 1.14, 95% CI 0.92 – 1.42). Very similar results were obtained when using the 10% cut-off point (OR = 1.13, 95% CI 0.96-1.32) and the 50% cut-off point (1.14, 95% CI 0.91 – 1.42).

The second study, AWES, provided occupational data on 750 females and included 215 different ISCO-68 codes. Fifty eight job codes in AWES (representing 82 women) could not be classified by the JEM as these occupations were not reported by BCEES participants. Of these additional occupations, six were classified by OccIDEAS as having exposure to early morning work only or graveyard shift only. A further seven were classified as having exposure to one or more of the mechanistic shiftwork variables. All of these occupations contained few individuals, and only one contained more than one exposed individual (Supplementary Table 1).

Sensitivity and specificity values were calculated for each of the cut–offs, 10%, 30% and 50% using the AWES data (Table 2). For most shiftwork variables, the 30% cut-off point performed best in terms of specificity and sensitivity. Sleep disturbances, lack of vitamin D, and early morning shift were difficult to estimate. For these variables, the specificity using the 30% cut-off was above 80%; however the corresponding sensitivity values were particularly poor, at 9.8%, 57.5% and 17.5% respectively.

TABLE 2: Sensitivity and specificity of the shiftwork JEM assessments applied to the Australian Workplace Exposure Study data, compared to the original assessments.

Shiftwork exposure variables	**N***	**cut point**	**Sensitivity (95% CI)**	**Specificity (95% CI)**
Light at night	76	10%	85.5 (75.6-92.6)	68.1 (64.2-71.8)
		30%	69.7 (58.1-79.8)	78.6 (75.0-81.8)
		50%	68.4 (56.8-78.6)	80.1 (76.6-83.2)

Phase shift	64	10%	81.0 (69.1-89.8)	66.6 (62.7-70.4)
		30%	69.8 (57.0-80.8)	77.7 (74.1-80.9)
		50%	68.3 (55.3-79.4)	78.2 (74.7-81.4)
Sleep disturbances	61	10%	73.8 (61.0-84.2)	71.0 (67.2-74.6)
		30%	9.8 (3.7-20.2)	98.0 (96.6-99.0)
		50%	1.6 (0.0-8.8)	99.2 (98.1-99.7))
Poor diet	68	10%	85.3 (74.6-92.7)	67.7 (63.8-71.4)
		30%	73.5 (61.4-83.5)	80.2 (76.8-83.3)
		50%	52.9 (40.5-65.2)	86.7 (83.7-89.3)
Lack of physical activity	52	10%	86.5 (74.2-94.4)	70.1 (66.3-73.7)
		30%	76.9 (63.2-87.5)	78.9 (75.5-82.1)
		50%	23.1 (12.5-36.8)	93.7 (91.5-95.5)
Lack of vitamin D	47	10%	78.7 (64.3-89.3)	75.7 (72.1-79.0)
		30%	57.5 (42.2-71.7)	85.8 (82.8-88.5)
		50%	2.1 (0.1-11.3)	98.6 (97.3-99.3)
Graveyard shift	109	10%	83.5 (75.2-89.9)	66.2 (62.1-70.1)
		30%	78.0 (69.0-85.4)	75.5 (71.7-79.0)
		50%	66.1 (56.4-74.9)	81.6 (78.1-84.7)
Early morning shift	117	10%	73.7 (64.6-81.5)	59.0 (54.8-63.2)
		30%	17.5 (11.1-25.8)	90.4 (87.7-92.8)
		50%	0.9 (0.0-4.8)	97.5 (95.8-98.6)

*Number of exposed workers in the Australian Workplace Exposure Study

DISCUSSION

We described the development of a JEM for the assessment of shiftwork exposures among women from a population-based case-control study, which assessed variables representing different aspects of shiftwork. These variables included exposure to light at night, phase shift, sleep disturbance, poor diet, lack of physical activity, lack of vitamin D, graveyard shifts, and early morning shifts. Of the 413 job titles reported by BCEES controls, 31% were associated with a non-zero probability of exposure to at least one of the shiftwork variables.

One measure of JEM quality is its ability to detect known associations.[32] We compared the OR for phase shift and breast cancer obtained from analysis of the original BCEES data (where exposure to shiftwork variables was assessed using automated expert assessment based on detailed job history information) with the OR obtained when exposure was assessed by applying the shiftwork JEM to the same study sample. Application of the JEM produced diluted ORs that were no longer statistically significant and quantitatively very similar across the 10%, 30% and 50% cut-off points. This suggests that the JEM has introduced non-differential misclassification that has biased the association towards the null.

Differences in the specificity of exposure definition between the variables may be a source of non-differential misclassification. Exposure estimates for variables that are more objectively defined, for example, graveyard shift refers specifically to work between midnight and 5am, can be viewed with greater confidence than those that are more subjective, or influenced by individual behaviour and preferences. It is also expected that the potential for misclassification of exposure is lower for these objectively defined variables, however, as phase shift was the only variable to show a significant association with breast cancer in BCEES, we were unable to test the effect of the JEM on other variables.

From the comparisons of the AWES assessments by the JEM with the original assignments using OccIDEAS it appeared that the 30% cut point was most appropriate to estimate exposure to the shiftwork variables. Specificity was considered a more important measure of the validity of exposure assessment than sensitivity because occupational exposures tend to be relatively rare in the general population.[21] For five of the eight shiftwork variables, the 30% cut point for exposure produced the most acceptable level of specificity (>75%) without markedly compromising sensitivity (>=70%). The exceptions were sleep disturbances, lack of vitamin D, and early morning shifts. At the 30% cut point, specificity for sleep disturbances was 98.0% and the sensitivity was just 9.8%. Chronotypes, or individual variations in sleep/wake times, vary with sex and age and may contribute to difficulties in estimating sleep disturbances among shift workers.[33] Indeed, chronotype has been shown to modulate the influence of certain shiftwork schedules on the experience of sleep disturbances among rotating shift workers.[34]

Individual behavioural preferences, for example leisure time spent outdoors, may also explain the poor results obtained for vitamin D. However, this argument would also hold for variables such as poor diet and lack of physical activity, which produced fair specificity and sensitivity at the 30% cut point. The final variable which was difficult to estimate was early morning shifts. The poor sensitivity of the JEM for this variable could be explained by differences in the time periods for which occupational information was collected between AWES (current job only) and BCEES (complete job history). Changes in working hours, organisation and conditions over time have possibly produced changes in the types and number of jobs that involve early morning work. There were 105 jobs involving early morning work in BCEES and only 24 of these corresponded with the jobs in AWES that reported early morning work. Possible changes in working time arrangements are also relevant when considering why poor sensitivity was apparent for the early morning shifts but not graveyard shifts. It is possible that the latter, unlike the former have remained relatively stable over time. Again this is supported by the data, which showed that all of the 48 BCEES jobs reporting graveyard work match up with the jobs in AWES that reported graveyard shiftwork.

Shiftwork JEMs have been created from routine surveys,[24, 35, 36] or from expert assessments of job histories.[25, 37] For JEMs created from routine data, the definitions of shiftwork exposure varied from involvement in night time working schedules,[24, 35] to working a rotating schedule with three or more possible shifts per day, or having work hours during the night (any hours between 1am and 4am) at least one day during the week prior to the survey.[24, 36] When applying JEMs created from routine surveys, studies used relatively high cut points (over 40%) in an attempt to diminish misclassification of the non-exposed.

For two shiftwork JEMs that were created using expert assessment of job histories, the authors provided comparisons of the JEM classifications to other exposure assessment methods. Pronk *et al*.[37] compared the JEM classifications to self-reported exposures, finding a higher prevalence of night shift work using the JEM (44% ever exposed to nightshift work) compared to self-reports (26%). Ji *et al*.[25] compared a JEM assessment of night shift work to urinary concentrations of 6-sulfatoxymelatonin, the primary urinary metabolite of melatonin that is increased after a normal night of sleep. A significant inverse association was found between the nightshift JEM scores and urinary 6-sulfatoxymelatonin levels in early morning samples, providing some evidence to support the JEMs validity in this population.[25]

These existing shiftwork JEMs focussed on the assessment of the probability of exposure to night shift work, rather than the more specific characteristics of shiftwork which may be the causative factors for health effects, working either in isolation or in combination.[28] For example, night jobs may involve working primarily in dark environments such as outdoor security work, dim environments such as hospital wards, or very bright environments such as airports or operating theatres. Hence, there may be substantial difference in variables such as the aggregate hours of exposure to bright light, and the number of bright light periods per 24 hours. Inconsistencies and broadness in the definition of shiftwork has been identified as a limitation of existing epidemiological literature, particularly in regard to studies of shiftwork and cancer.[3] In order to overcome complexities in uniformily defining and assessing shiftwork exposure, an approach that considers the biological mechanisms through which shiftwork effects health is warranted. As such, the development of this JEM, which considers several biologically plausible mechanisms will not only enhance understanding of the mechanism by which shiftwork produces ill health, but also provides a standard set of indicators which can be employed in future studies.

Despite the potential benefits of JEMs for population-based studies, the limitations of this approach are noteworthy. A JEM cannot account for variability of exposure within job codes. It is known that occupational exposures can vary between workers employed in the same job, even in the same location.[38] This suggests that individual behaviour is an important determinant of exposure and a determinant that is not adequately captured by JEMs. This may be particularly relevant to some of the variables in our study that are highly dependent on personal behaviours, such as poor diet, lack of physical activity, and lack of vitamin D and may contribute to the misclassification observed when applying the JEM to other data.

In addition, the shiftwork JEM presented here has been produced using data obtained from a study of Australian women. A number of ISCO-68 codes were not reported by participants in BCEES and therefore exposure information was missing. Many of these occupations tend to be male-dominated and it is likely that some would be very rare in general. Furthermore, many of these jobs would be unexposed to shiftwork, so their exclusion from the JEM is not of great concern. Regardless of these points, it may not be appropriate to apply the JEM in male populations and the frequency of shiftwork exposures in predominately male occupations may not be estimable.

It should also be noted that some occupational codes included in the JEM contain very small numbers and therefore the probability of shiftwork exposure for these codes should be viewed with caution (Table 1). We are more confident in the exposure estimates for occupations with greater n-values, compared to less common jobs. Lastly, it is possible that coding errors in assigning ISCO-68 codes to occupational data could contribute to misclassification of exposure.

These caveats will need to be taken into account when applying this JEM to other data in future studies and researchers are encouraged to carefully review the exposure assessment. This is particularly important when applying this JEM to study populations in other countries. Researchers are advised to manually check those jobs not captured by the JEM, with a clearly defined rule for assigning exposure such as using the hierarchical structure of ISCO. Researchers are also advised to double check the exposure classification for jobs that are common in their study population. In a study investigating the applicability of a British JEM in a Finnish population, Kauppinen *et al*.[39] found that the British JEM performed satisfactorily for common exposures, that is, those with a prevalence of at least 10%. Rules for exposure assessment may also vary depending on differences in the industrial environment and processes between countries. The prevalence of exposure and the applicability of this JEM in other populations or countries are likely to be influenced by the economic structure, sex and age distribution of that population.[39] Researchers are also advised to consider the effect of changes in working conditions over time and the influence this may have on the applicability of some of the JEM variables (particularly the early morning shifts) to their study. This also extends to changes in the types of jobs that women are involved in and the expansion of female workers in to industries that were traditionally dominated by male workers.

For future JEMs of this kind, we recommend the development of more objective definitions of exposure for the shiftwork variables, to reduce the potential for misclassification due to individual preferences and interpretations of exposure.

Despite these caveats, our JEM is likely to provide an alternative means of assessing exposure to shiftwork related variables in the absence of detailed job histories and exposure data. The shiftwork JEM provides a useful tool for future studies as it provides a standard set of indicators that reflect biologically plausible mechanisms for the potential impact of shiftwork on health.

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The full JEM may be accessed on request.

Competing interests

None.

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