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Occupational Health

Is shift work associated with a higher risk of overweight or obesity? A systematic review of observational studies with meta-analysis

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Abstract

Background: An increasing number of original studies suggest that exposure to shift work could be associated with the risk of overweight and obesity, but the results remain conflicted and inconclusive. This study aimed to quantitatively synthesize available epidemiological evidence on the association between shift work and the risk of overweight and obesity by a meta-analysis.

Methods: The authors searched PubMed, Embase and the reference lists of all included studies up to April 2017, with a verification search in December 2017. Inclusion criteria were original studies that reported odds ratios, relative risks or hazard ratios (ORs, RRs or HRs, respectively) of at least one outcome of overweight or obesity. Summary risk estimates were calculated by random-effect models.

Results: Twenty-six studies (7 cohort studies, 18 cross-sectional studies and 1 case–control study) involving 311 334 participants were identified. Among these studies, the cut-off points of overweight and obesity varied greatly, so the heterogeneity was substantial; however, the results were stable. Shift work was found to be positively associated with the risk of overweight [RR: 1.25; 95% confidence interval (95% CI): 1.08–1.44] and obesity (RR: 1.17; 95% CI: 1.12–1.22).

Conclusions: Individuals involved in shift work are more likely to become overweight or obese. Appropriate preventive interventions in the organization of shift schedules according to ergonomic criteria would allow shift workers to avoid potential health impairment.

Key words: shift work, overweight, obesity, meta-analysis, prevention

Key Messages

- This meta-analysis indicated an association between shift work and increased overweight/obesity risk.
- The risk of becoming overweight on night-shift work is much higher than for rotating-shift work.
- We suggest that optimized interventions are needed in the organization of shift schedules to protect workers from overweight/obesity.

Introduction

Shift work (SW) refers to a job schedule in which employees work hours other than the normal working schedule of 9 a.m. to 5 p.m.[1] The full spectrum of SW comprises regular evening or night shifts, split shifts, rotating shifts, on-call or casual shifts, irregular shifts, 24-hour shifts and other non-day shifts. It has been reported that 36.1% of employees undertake SW in China and Korea.[2] A study on working conditions showed that nearly 20% of employees in industrialized countries were involved in SW.[3] Previous studies have showed that SW is associated with negative health outcomes.[4,5] SW has been implicated in disrupting the circadian rhythm,[6] which may impair glucose metabolism and lipid homeostasis.[7] An irregular sleep–wake cycle could influence hormones related to appetite regulation.[7,8] SW has also been found to interrupt workers' recovery from fatigue and to prevent performance of regular exercise.[9] Metabolic disorders, altered eating behaviour[10,11] and less exercise[4] may result in overweight and obesity among shift workers.

Persisting stereotypes describe overweight and obese people as lazy, less self-disciplined and incompetent.[12] In the workplace, obesity is an important driver of costs associated with absenteeism, healthcare claims, sick leave, injuries and disability.[13,14] The high prevalence of overweight and obesity is particularly concerning because the links between overweight/obesity, poor health outcomes and all-cause mortality are well established. Overweight and obesity increase the likelihood of diabetes, hypertension, coronary heart disease, stroke, obstructive sleep apnea, certain cancers and osteoarthritis.[15] Overweight and obesity were estimated to account for 3.4 million deaths per year and 93.6 million disability-adjusted life years (DALYs) in 2010.[16]

Growing attention has been paid by the public to the influence of SW on the risk of overweight and obesity,[17–27] whereas the findings have remained inconsistent or even conflicting. The majority of studies report a positive relationship,[17,18,20–22,24,27–32] whereas other studies show no obvious association.[19,23,25,30,33–41] The influence of SW on overweight and obesity is still unclear. A meta-analysis in 2014 showed that night SW was associated with the risk of metabolic syndrome (MetS).[42] However, the evidence was limited by retrieving only 13 studies on MetS; since then, a number of additional studies have been published. Recently, a published meta-analysis that considered overweight and obesity as a whole reported that night SW was positively related to the risk of obesity and overweight.[43] However, there are some differences between overweight and obesity, such as the definitions and health consequences. The relationship between SW and overweight and obesity has not been systematically evaluated. Hence, we conducted a comprehensive meta-analysis of 27 observational studies to quantify the association between SW and obesity and overweight, respectively, and to provide evidence-based information for managers in charge of working time organization to effectively protect workers from overweight/obesity.

Methods

No protocol exists for this meta-analysis.

Ethics

Ethical approval was not required for this systematic review.

Literature search strategy

We conducted the meta-analysis according to the MOOSE guideline.[44] We sought studies that reported risk estimates for the association between SW and at least one outcome of overweight or obesity. Outcomes were typically defined by primary study authors using country-specific iterations of the International Classification of Disease coding system. We imposed no limitation by study design, regional origin or nature of the control group, which could include day workers or the general population.

We systematically searched PubMed and Embase from inception until December 2017. We used database-specific subject terms and keywords to generate an initial list of articles for scrutiny. We also scrutinized the reference lists of all eligible articles. Two health information specialists (Q.L. and J.S.) designed and implemented the search in consultation with the rest of the team. Two reviewers (P.D. and T.Y.) screened citations and assessed articles independently for inclusion; disagreements were settled through consultation with a third reviewer (Z.L.).

Study selection criteria

Studies meeting the following criteria were included in the meta-analysis: (i) the research design was cohort, case–control or cross-sectional; (ii) any type of SW was an exposure variable; (iii) the endpoint of interest was the prevalence or incidence of overweight or obesity; and (iv) the study reported the risk estimates and corresponding 95% CIs for the association between SW and overweight or obesity. Reviews, animal studies, clinical trials, commentaries and letters were excluded. Studies involving non-work-related or involuntary night-time light exposure were also excluded.

Data extraction from studies with aggregate data

We extracted details on the name of the first author, year of publication, region, study design, definition of shift workers and references, characteristics of participants, outcome measurements, number of participants and cases, risk estimates with 95% CIs and covariates adjusted in the statistical analysis. We classified SW schedules according to the primary study methodological descriptions as night, rotating and mixed. Two reviewers (Q.L. and T.Y.) extracted all outcome data independently after reformulation of study citation information. Disagreement among reviewers was discussed and agreement was reached by consensus.

Quality appraisal

We appraised all the included studies using the Newcastle-Ottawa Scale 10,[45] which is a nine-point scoring system used to assess the quality of non-randomized studies included in a systematic review and/or meta-analysis. A high-quality study was defined as a study with at least seven points. Disagreements on quality assessment were resolved by discussion among the authors.

Statistical analysis

The relative risks (RRs) and 95% confidence intervals (CIs) were considered as the effect size in this meta-analysis. We calculated summary RRs by synthesizing across the shift schedules categorized in each study. A random-effects model was used to pool the effect estimates. RRs for overweight and obesity were calculated with 95% CIs. Subgroup analyses, hypothesized a priori, were conducted using a statistical test of interaction.[46] Studied subgroups included study design (cohort, cross-sectional study and case–control study), type of SW, region of study, gender of participants and adjusted variables. We used the I^2 statistic to measure heterogeneity. Values of 0–30% represented minimal heterogeneity, 31–50% represented moderate heterogeneity and >50% represented substantial heterogeneity.[47] We assessed our results with the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework.[48]

Potential publication bias was assessed with visual inspection of the funnel plot, the Begg correlation test and the Egger linear regression test. All statistical analyses were performed with STATA.11.0 (Stata Corp, College Station, Texas, USA). All tests were two-sided, with a significance level of 0.05.

Results

Literature search

The literature search identified 1493 citations from PubMed and 3559 from Embase, of which 553 were selected for further review (see Figure 1). Of these, we retrieved 56 articles in full and rated 26 as eligible for the review; one paper included a cohort and a case–control study. In total, there were 27 eligible published studies with aggregate data, of which 7 were cohort studies, 19 were cross-sectional studies and 1 was a case–control study.

Characteristics and quality of the included studies

The studies included 311 334 participants, with 10 473 overweight cases and 51 024 obesity cases. The study publication years ranged from 1999 to 2017. Briefly, we identified 27 primary studies of SW and risk of overweight/obesity. Among the studies included, shift schedules were classified as night shifts ($n = 5$), rotating shifts ($n = 18$) and mixed schedules ($n = 4$). All studies ($n = 27$) used non-shift

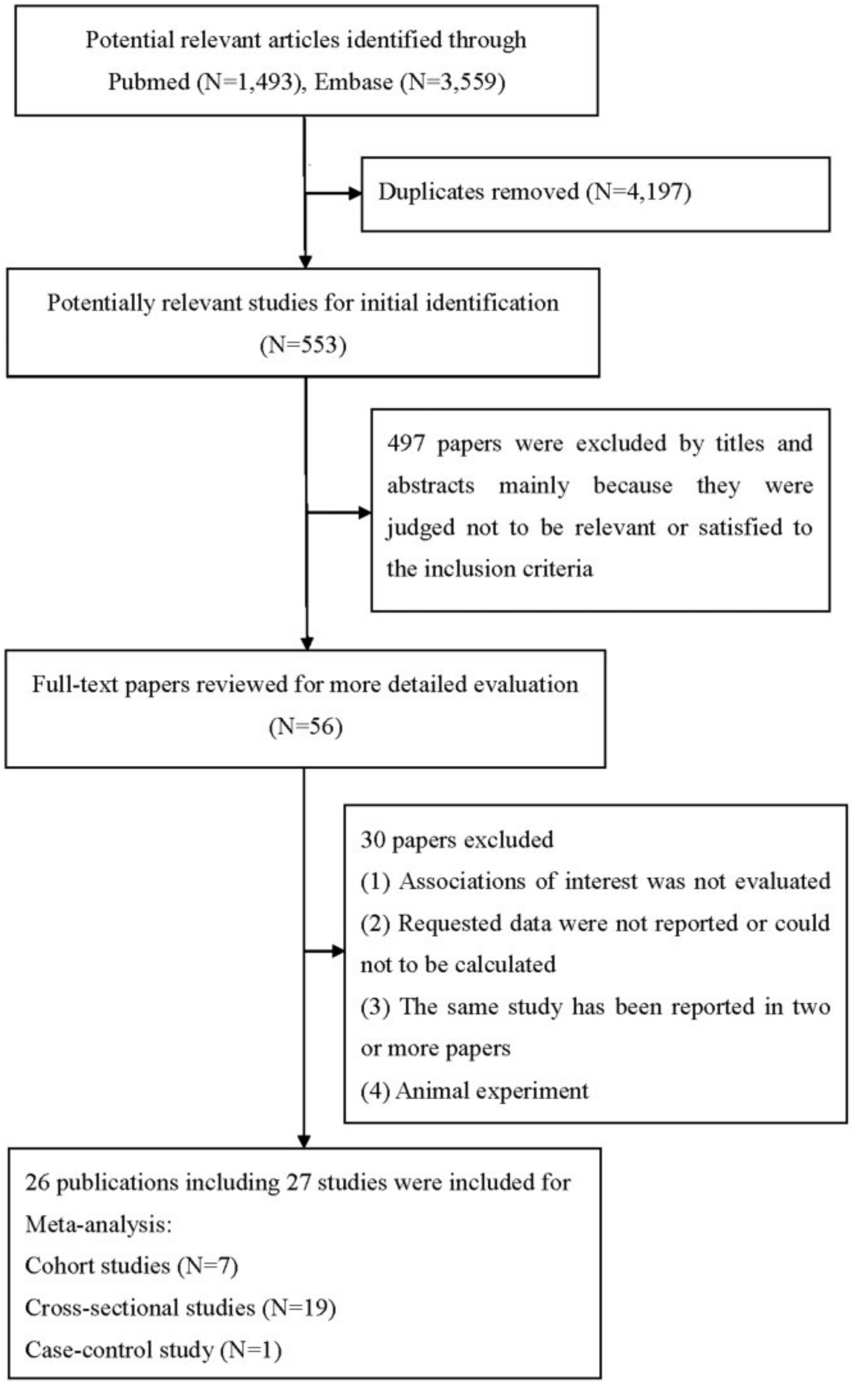

Figure 1. Flow diagram of identification of relevant observational studies of shift work in relation to the risk of overweight and obesity.

workers as the reference category. Eight studies were conducted in Europe, eight in Asia, six in North America and three in South America; the remaining two were multinational. Five and 9 studies only reported separate outcomes of males and females, respectively, and 13 studies reported the outcomes of both genders. The quality scores of these studies appraised with the Newcastle-Ottawa Scale 10 ranged from 6 to 10. Overall, 7 studies had a score of 9, 11 had a score of 8, 6 had a score of 7 and 3 had a score of 6, which led to an average score of 7.81 points. Detailed characteristics and quality assessments of these studies are presented in Table 1.

Summary of the definitions of SW, overweight and obesity

Most studies reported the relationship between rotating SW and obesity,[17–20,24,25,27–29,31,32,34–37,39,40,49] whereas

Table 1. Characteristics of studies included in the meta-analysis of shift work in relation to risk of overweight and obesity

Study	Year	Study design	Country	Gender	Participants	Cases of obesity	Cases of overweight	Type of shift work	Assessment of obesity	Assessment of overweight	Adjustment of covariates
Grundy *et al.*	2017	Cross-sectional	Canada	male	1561	248	854	Rotating	BMI ≥ 30 kg/m^2	BMI ≥ 25 kg/m^2	Age, education, marital status, family income, smoking status, physical activity, energy consumption
Barbadoro *et al.*	2016	Cross-sectional	Italy	Male and female	36 814	3427	NA	Rotating	BMI ≥ 30 kg/m^2	NA	Gender, age, education, household BMI, leisure time physical activity, smoking habit, nutritional habit, drugs/chronic conditions
Gomez-Parra *et al.*	2016	Cross-sectional	Colombia	Male and female	200	14	160	Rotating	BMI ≥ 30 kg/m^2	BMI ≥ 25 kg/m^2	Gender, age, work related stress, current smoking status, occupation, educational level, years working in shifts
Yoon *et al.*	2016	Cross-sectional	Korea	Female	42 234	7249	NA	Rotating	BMI > 25 kg/m^2	NA	Age, marital status, education level, household income, smoking history, alcohol intake, physical activity and sleep duration
Ramin *et al.*	2015	Cohort	USA	Female	54 724	15 983	NA	Rotating	BMI ≥ 30 kg/m^2	NA	Age, education level of the nurse's spouse/partner, physical activity, chronotype, body mass index at age 18
McGlynn *et al.*	2015	Cohort	Canada	Female	1097	90	268	Rotating	BMI ≥ 30 kg/m^2	BMI ≥ 25 kg/m^2	Population-based sample was adjusted for education and age; alumni cohort sample was adjusted for smoking, parity and age
Buchvold *et al.*	2015	Cross-sectional	Norway	Male and female	2059	2038	NA	Night	BMI > 30 kg/m^2	NA	Age, sex, exercise
Givens *et al.*	2015	Cross-sectional	USA	Male and female	1593	497	464	Rotating	BMI ≥ 30 kg/m^2	BMI ≥ 25 kg/m^2	Age (continuous), gender, education, and race/ethnicity
McGlynn *et al.*	2015	Case–control	Canada	Female	1611	306	477	Rotating	BMI ≥ 30 kg/m^2	BMI ≥ 25 kg/m^2	Population-based sample was adjusted for education and age; alumni cohort sample was adjusted for smoking, parity and age

(Continued)

Table 1. Continued

Study	Year	Study design	Country	Gender	Participants	Cases of obesity	Cases of overweight	Type of shift work	Assessment of obesity	Assessment of overweight	Adjustment of covariates
Neilsztramko	2015	Cross-sectional	Canada	Male and female	4323	1050	NA	Mixed	BMI $\geq$ 30 kg/m^3	NA	Age, sex and children in the household
Peplonska *et al.*	2015	Cross-sectional	Poland	Female	724	168	289	Night	BMI $\geq$ 30 kg/m^2	BMI $\geq$ 25 kg/m^2	Age, smoking, pack years, marital status, body silhouette at age 20
Son *et al.*	2015	Cross-sectional	Korea	Male and female	2952	742	NA	Rotating	TBF% males: $\geq$25.7%, females: $\geq$36.0%	NA	Age, education, income, marital status, alcohol intake, smoking, energy intake, physical activity, sleep time, stress, menopausal status, work hours, stability of work
Balieiro *et al.*	2014	Cross-sectional	Brazil	Male	150	NA	80	Night	BMI $\geq$ 25 kg/m^2	WC $\geq$ 94 cm	Age
Peplonska *et al.*	2014	Cross-sectional	Poland	Male and female	605	114	289	Night	BMI $\geq$ 30 kg/m^2	BMI $\geq$ 25 kg/m^2	Age, marital status and education
Barbadoro *et al.*	2013	Cross-sectional	Italy	Male	339	NA	241	Rotating	NA	BMI > 24.9 kg/m^2	Age, family history of obesity, alcohol consumption and physical activity
Kim *et al.*	2013	Cross-sectional	Korean	Female	9989	736	5287	Rotating	BMI $\geq$ 25 kg/m^2	BMI $\geq$ 23 kg/m^2	Age, current smoking status, drinking habit, marital status, family income, education, dietary habits, regular exercise, sleep problems, self-perceived health status
Macagnan *et al.*	2012	Cross-sectional	Brazil	Male and female	1206	NA	800	Night	NA	BMI $\geq$ 25 kg/m^2	Demographic variables, socio-economic variables and parental overweight, behavioural variables (number of meals) and sleep characteristics
Zhao *et al.*	2012	Cross-sectional	Multinational	Female	2086	1132	661	Mixed	BMI $\geq$ 30 kg/m^2	BMI $\geq$ 25 kg/m^2	Diet quality, physical activity, smoking status, alcohol consumption, work pattern, general physical and mental health

(Continued)

Table 1. Continued

Study	Year	Study design	Country	Gender	Participants	Cases of obesity	Cases of overweight	Type of shift work	Assessment of obesity	Assessment of overweight	Adjustment of covariates
Itani *et al.*	2011	Cohort	Japan	Male and female	22 743	10 420	NA	Rotating	BMI ≥ 25 kg/m^2	NA	Age class, eating habits, alcohol consumption, smoking habit, exercise habit, mental complaints, hypertension, hyperglycemia, hypertriglyceridemia and hypo-HDL cholesterolemia
Kubo *et al.*	2011	Cohort	Japan	Male	9912	3319	NA	Rotating	BMI ≥ 25 kg/m^2	NA	Age, smoking, drinking and physical activity during leisure time
Bushnell *et al.*	2010	Cross-sectional	Multinational	Male and female	26 442	NA	NA	Mixed	BMI ≥ 30 kg/m^2	NA	Age group, sex, marital/living status, job tenure and occupational group
Chen *et al.*	2010	Cross-sectional	China	Female	1838	NA	NA	Mixed	BMI ≥ 25 kg/m^2	NA	Age, smoking, drinking, education and duration of work
Oberlinner *et al.*	2009	Cohort	Germany	Male	31 346	2431	NA	Rotating	ICD-10	NA	Age, job level, cigarette smoking and alcohol intake
Watari *et al.*	2006	Cohort	Japan	Male and female	25 312	1060	NA	Rotating	BMI ≥ 26.4 kg/m^2	NA	Smoking, age, work style, one-way commuting time, consumption of alcohol, sleeping hours, exercise, eating style
Chee *et al.*	2004	Cross-sectional	Malaysia	Female	1612	NA	603	Rotating	NA	BMI ≥ 25 kg/m^2	Age
Karlsson *et al.*	2001	Cross-sectional	Sweden	Male and female	27 485	NA	NA	Rotating	BMI ≥ 30 kg/m^2	NA	Age, education
van Amelsvoort *et al.*	1999	Cohort	Netherlands	Male and female	377	NA	NA	Rotating	BMI ≥ 25 kg/m^2	NA	Smoking

BMI, body mass index; NA, not available; WC, waist circumstance.

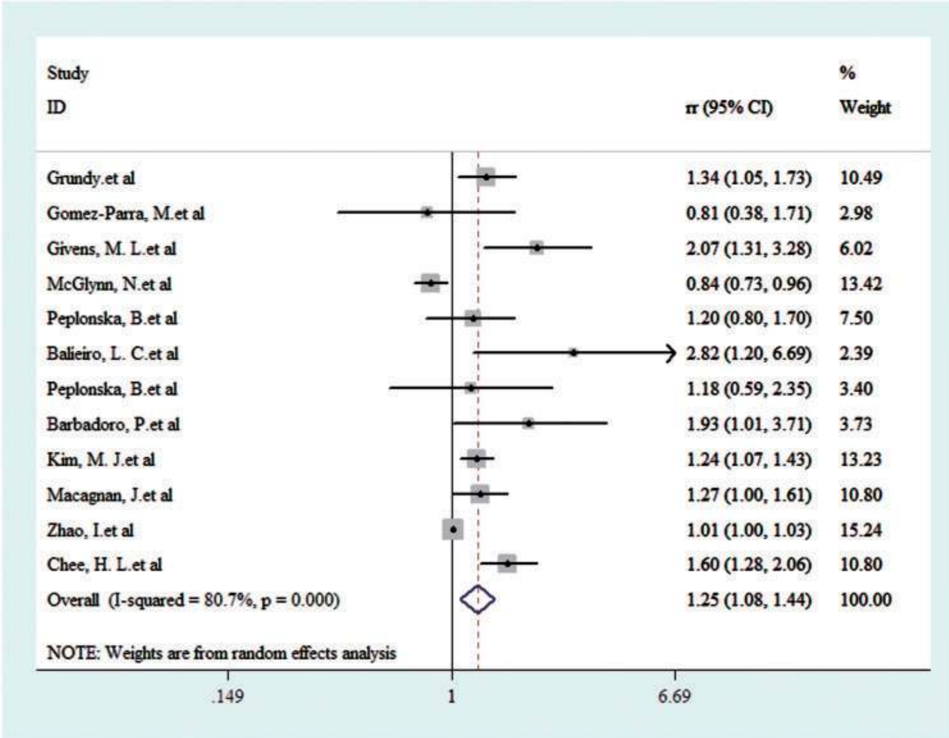

Figure 2. Forest plot of the association between shift work and overweight.

five studies showed outcomes of night-only SW,[22,23,30,38,41] two studies reported results of rotating shift and night shift separately[21,33] and one study reported outcomes of night shift and day shift separately.[50] Eight studies defined overweight as a body mass index (BMI) ≥ 25 kg/m^2.[21,27,30,32,37–41] Barbadoro, Kim and Balieiro defined overweight as BMI > 24.9 kg/m^2, BMI ≥ 23 kg/m^2 and waist circumstance ≥ 94 cm, respectively.[22,29,36] Eleven studies defined obesity as BMI ≥ 30 kg/m^2.[18,21,27,30–33,36–39,49] Six defined the presence of obesity as BMI ≥ 25 kg/m^2 [17,22,29,34,50,51] and the remaining four studies defined obesity as BMI > 30 kg/m^2,[23] BMI >25 kg/m^2,[25] BMI ≥ 26.4 kg/m^2,[19] and by total body fat percentage,[35] respectively. Only one study defined obesity according to the tenth revision of the International Classification of Diseases (ICD-10).[20]

SW increases risk of overweight and obesity

Figure 2 shows the combined RR from the random-effect model for overweight in relation to SW. Twelve studies described the association between SW and the risk of overweight. Of the 12 studies, 6 showed no obvious relationship or an inverse association between SW and the risk of overweight, whereas 6 other studies reported a positive relationship. The pooled RR was 1.25 (95% CI: 1.08–1.44, $I^2 = 80.7\%$). A meta-analysis was performed to estimate the association between SW and the risk of obesity by combining results from all eligible studies, giving a summary RR of 1.17 (95% CI: 1.12–1.22; $I^2 = 92.2\%$) (see Figure 3). Only three studies reported the dose–response relationship between SW and obesity[27,30,31] and the information is inadequate for further dose–response analysis, but we could indicate that a higher combined RR was associated with a higher frequency of monthly night shifts (at least eight nights/month) compared with the lower one. Peplonska and Kim indicated a positive dose–response relationship between years of SW and obesity risk.[27,29,30]

Subgroup analyses and sources of heterogeneity

We performed subgroup analyses to assess whether specific study characteristics influenced the association between SW and overweight/obesity. As shown in Table 2, the increased risk for overweight was more evident in the night-shift group (RR: 1.38; 95% CI: 1.06–1.80). SW was associated with increased risks of obesity in most subgroups. Table 3 presents a higher pooled RR for obesity in the rotating-shift group (RR: 1.18; 95% CI: 1.08–1.29). Additionally, subgroup analyses suggested a stronger association between SW and obesity for cohort studies (RR: 1.16; 95% CI: 1.03–1.31) than for cross-sectional studies (RR: 1.11; 95% CI: 1.07–1.15).

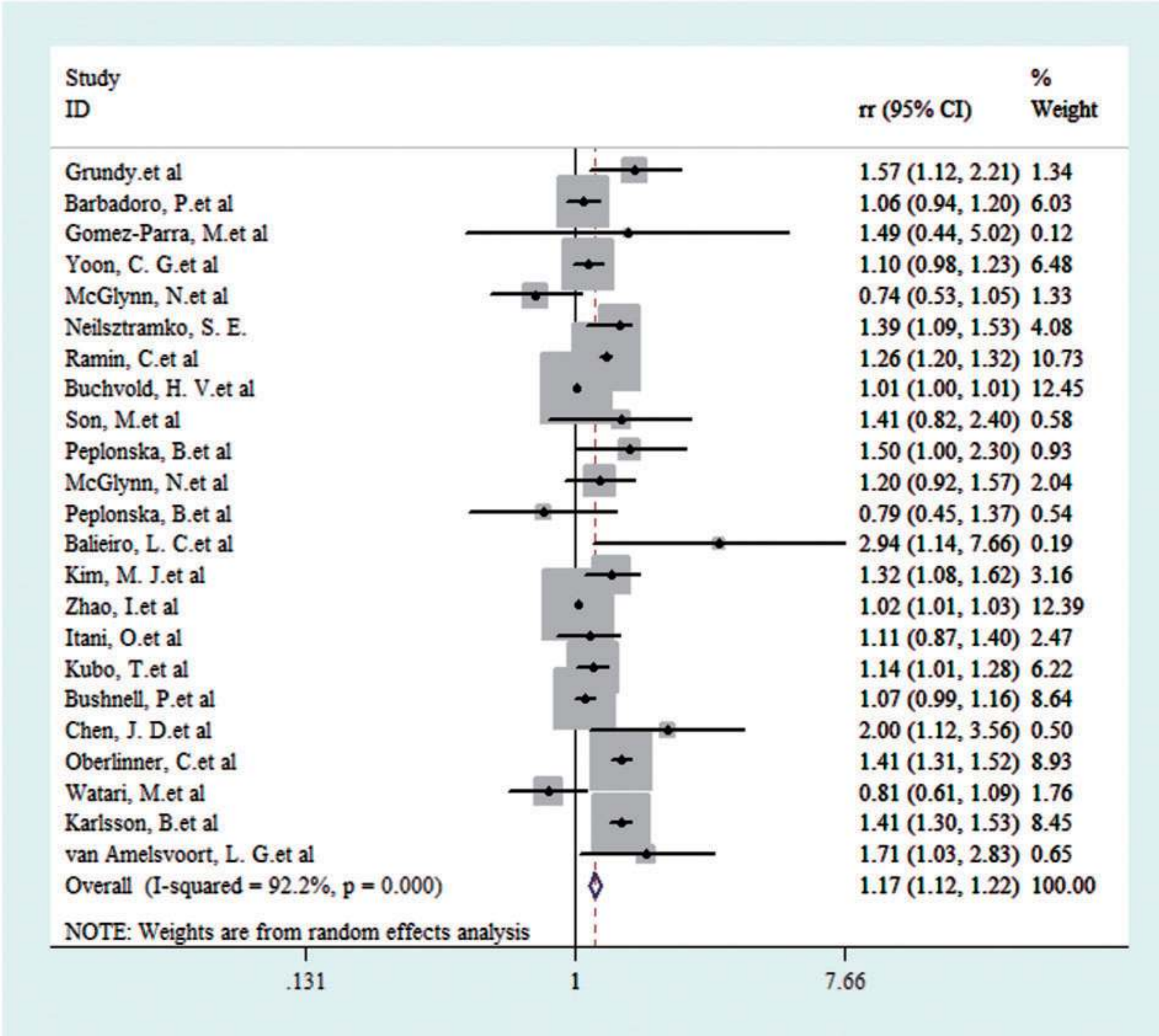

Figure 3. Forest plot of the association between shift work and obesity.

Table 2. Subgroup analyses of relative risks of overweight according to shift-work status

Study groups	*N*	Relative risk (95% CI)	Heterogeneity		*P*-value for interaction
			I^2	*P*	
All	13	1.25 (1.08, 1.44)	80.7	0	NA
Type of shift work					
Rotating-shift work	8	1.21 (1.02, 1.43)	73.2	0	0.860
Night-shift work	5	1.38 (1.06, 1.80)	28.5	0.231	
Gender					
Female	6	1.14 (0.97, 1.35)	84.3	0	0.913
Male	5	1.46 (0.98, 2.15)	51.2	1.104	
Region					
Europe	4	1.32 (0.98, 1.77)	0	0.432	0.873
North America	3	1.27 (0.79, 2.06)	90.5	0	
South America	3	1.35 (0.80, 2.28)	57.2	0.097	
Asia	2	1.38 (1.08, 1.77)	68.9	0.073	

Stratified meta-analysis of shift work and the risk of overweight. All groups were compared with 8-hour day-shift employees as the reference category. CI, confidence interval; *N*, number of studies; *P*, *P*-value for heterogeneity; NA, not available.

Table 3. Subgroup analyses of relative risks of obesity according to shift-work status

Study groups	*N*	Relative risk (95% CI)	Heterogeneity I^2	Heterogeneity *P*	*P*-value for interaction
All studies	23	1.17 (1.12, 1.22)	92.2	0	NA
Type of shift work					
Day-shift work	2	1.14 (0.79, 1.64)	61.3	1.108	0.82
Night-shift work	7	1.05 (1.00, 1.10)	81	0	
Rotating-shift work	17	1.18 (1.08, 1.29)	91.7	0	
Study design					
Cohort	7	1.16 (1.03, 1.31)	81.2	0	0.87
Cross-sectional	15	1.11 (1.07, 1.15)	87.7	0	
Case–control	1	1.20 (0.92, 1.57)	NA	NA	
Gender					
Female	13	1.19 (1.06, 1.34)	90.8	0	0.938
Male	9	1.27 (1.10, 1.46)	81.9	0	
Geographical location					
Asia	7	1.14 (1.02, 1.28)	48.9	0.068	0.87
North America	5	1.23 (1.05, 1.44)	67.6	0.015	
Europe	7	1.23 (1.02, 1.48)	96	0	
South America	2	2.27 (1.07, 4.81)	0	0.389	
Participants					
Medical staff	6	1.09 (1.04, 1.03)	94.7	0	0.317
Other workers	16	1.21 (1.10, 1.33)	59.8	1.115	
Number of cases					
<1000	7	1.27 (1.09, 1.48)	47.5	0.168	0.783
1000–5000	6	1.08 (1.04, 1.12)	94.2	0	
>5000	3	1.18 (1.06, 1.31)	63	0	
Cut-off of obesity					
BMI > 25 kg/m^2 or ≥ 25 kg/m^2	7	1.23 (1.08, 1.39)	49.7	0.064	0.73
BMI > 30 kg/m^2 or ≥ 30 kg/m^2	12	1.12 (1.08, 1.16)	74.6	0.047	
Other cut-offs	3	1.17 (0.78, 1.74)	84.3	0.002	
Adjustment for physical exercise					
Yes	11	1.08 (1.05, 1.13)	78.3	0.032	0.183
No	10	1.30 (1.13, 1.50)	79.8	0	
Adjustment for energy intake					
Yes	8	1.10 (1.02, 1.20)	77.2	0.036	0.364
No	13	1.23 (1.09, 1.39)	95.1	0	

Stratified meta-analysis of shift work and the risk of obesity. All groups were compared with 8-hour day-shift employees as the reference category. CI, confidence interval; *N*, number of studies; *P*, *P*-value for heterogeneity; NA, not available; BMI, body mass index.

As substantial heterogeneity was found among the included studies, we conducted subgroup analyses and identified the potential cause of heterogeneity by various factors, such as gender, region of study, type of SW, study design and number of cases. Subgroup analyses suggested that different types of SW might be the main cause of heterogeneity for overweight. For night SW, no obvious heterogeneity was found. For rotating SW involving night shift, the heterogeneity was substantial. It is self-evident that the specific schedules of rotating SW differ greatly among different occupations and positions. The endpoints of obesity were different between studies, which might contribute to the heterogeneity of obesity under the influence of SW. For example, for three studies with cut-offs of obesity other than BMI, the combined RR was 1.17 (95% CI: 0.78–1.74), whereas the pooled RR of studies with cut-offs of BMI > 25 kg/m^2 and BMI ≥ 25 kg/m^2 was 1.23 (95% CI: 1.08–1.39), and the accumulated RR of studies with endpoints of BMI > 30 kg/m^2 and BMI ≥ 30 kg/m^2 was 1.12 (95% CI: 1.08–1.16).

Sensitivity analyses

When we excluded the studies of Oberlinner *et al.*[20] and Son *et al.*,[35] in which the ICD-10 and total body fat percentage definitions were used, the pooled RR of SW and obesity was 1.16 (95% CI: 1.11–1.21). We then excluded any single study in turn and combined the results of the

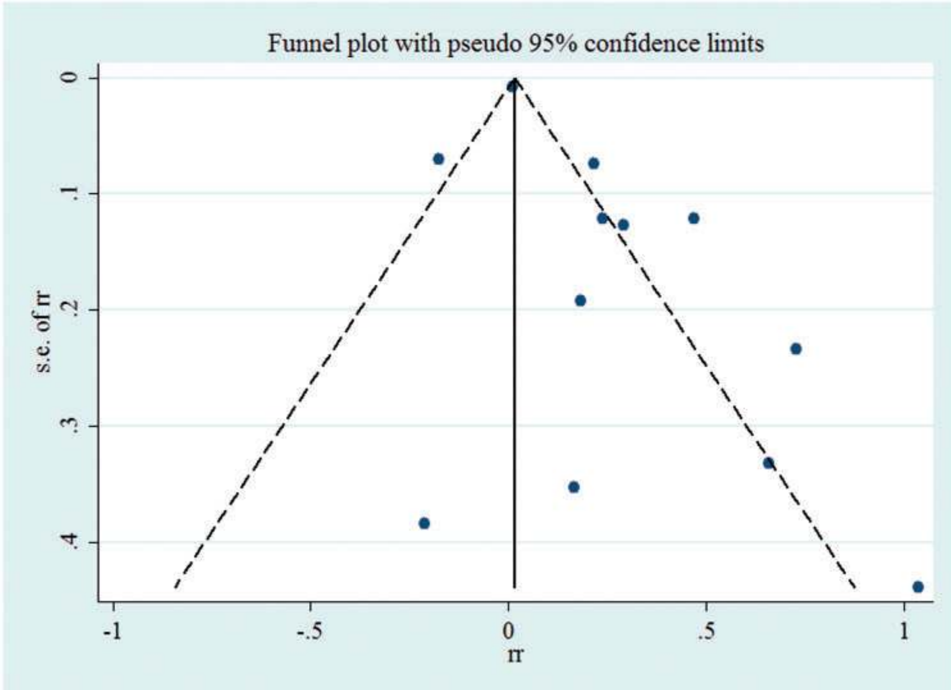

Figure 4. Funnel plot for studies of shift work in relation to overweight risk.

remaining included studies, and the overall summary RRs for overweight and obesity were not substantially altered. The summary estimates derived from subsequent sensitivity analyses for overweight ranged from 1.19 (95% CI: 1.02–1.38) to 1.35 (95% CI: 1.13–1.62) and for obesity they ranged from 1.16 (95% CI: 1.11–1.21) to 1.17 (95% CI: 1.12–1.22).

Publication bias

There was no obvious publication bias detected by Begg's and Egger's tests ($P = 0.047$ for overweight, $P = 0.004$ for obesity) (Figures 4 and 5).

Discussion

In the current systematic review and meta-analysis, a total of 27 independent studies involving 311 334 participants (10 473 overweight cases and 51 024 obesity cases) were identified for examination. Evidence from these studies suggests that shift workers might have an increased risk of overweight and obesity, by 25% and 17%, respectively. This result for obesity is consistent with a previous meta-analysis by Wang *et al.*,[42] which reported an increased risk of obesity of 1.66 (95% CI: 1.02–2.71) based on six studies. However, our meta-analysis included 16 additional studies on obesity with a much larger sample size. Additionally, Wang *et al.* did not do subgroup analysis of obesity, nor did they quantitatively analyse the association between SW and overweight. Recently, another published meta-analysis found the pooled odds ratio of night SW was 1.23 (95% CI: 1.17–1.29) for risk of obesity and overweight.[43] Although the meta-analysis included original studies about abdominal obesity, unfortunately it omitted seven studies due to the searching strategy and the definitions of outcomes. The present meta-analysis analysed the association between overweight as well as obesity and SW patterns. We found that night SW was positively associated with overweight 1.38 (95% CI: 1.06–1.80), whereas rotating SW increased the risk of obesity 1.18 (95% CI: 1.08–1.29). Taken together, our meta-analysis may be the latest evidence of association of SW with overweight/obesity to date.

Circadian disruption can be the biological explanation for the pathogenesis of obesity. Long-term exposure to SW might disturb the normal circadian rhythm, which might impair glucose metabolism and lipid homeostasis.[7] Although the mechanism linking obesity to circadian disruption has not yet been fully understood, both animal experiments and human studies have indicated that disruption of the circadian rhythm might be causal for obesity.[52–54] Melatonin is an important mediator of circadian disruption resulting in SW and obesity. Melatonin production is promoted in darkness but suppressed by light in the night, so SW including night shift could inhibit the secretion of melatonin. An animal study reported that the

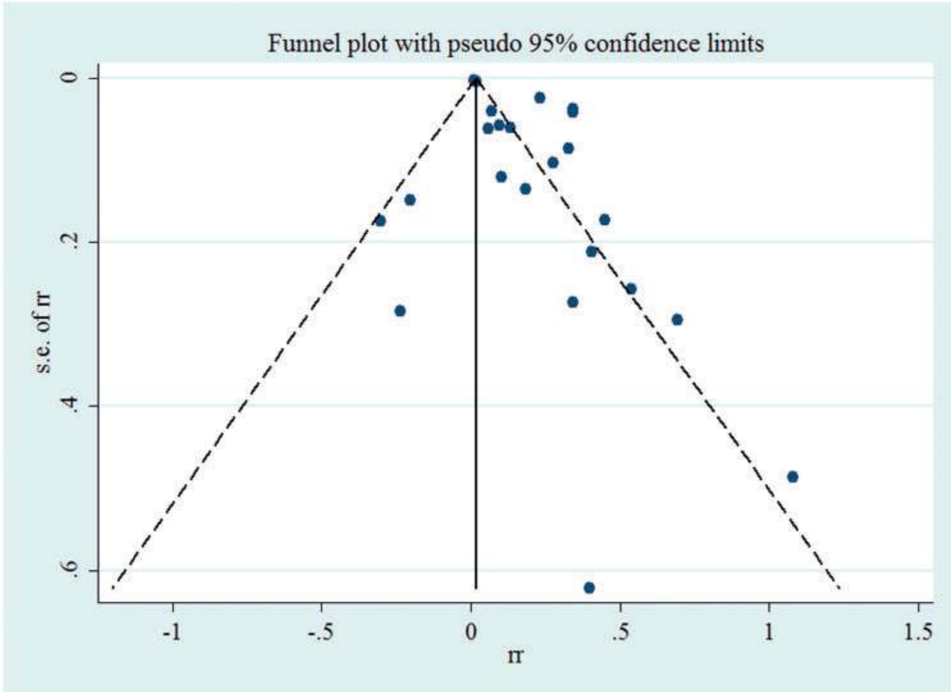

Figure 5. Funnel plot for studies of shift work in relation to obesity risk.

reduced production of melatonin was associated with metabolic disturbance.[55] Leptin acts as a natural appetite suppressor, aiding in the regulation of energy intake and expenditure by inhibiting appetite and speeding up metabolism.[56] Additionally, Qin *et al.*[57] indicated that the disturbance of circadian rhythms leads to the impairment of insulin response to glucose, and the changes of melatonin and leptin were highly consistent with those of night-eating syndrome, which would result in excess weight. The main findings of our study suggested that rotating-shift workers had an increased risk of obesity of 16% compared with the reference groups. Weight gain can provide an 'infrastructure' for health disorders. Therefore, shift schedules should be arranged according to ergonomic criteria to limit negative effects on hormone secretion and health.

Sleep deprivation—another plague of the modern world—is recognized to be involved in the pathogenesis of obesity.[58] Epidemic studies have revealed an association between chronic sleep deprivation and long-term weight gain.[59,60] Sleep disturbance, which adversely influences hormonal rhythms and metabolism, also contributes to overweight and obesity.[7] Several pathways could link sleep duration to obesity, including increased food intake, reduced energy expenditure and alterations in levels of appetite-regulating hormones, such as leptin and ghrelin.[61] Sleep deprivation has been associated with decreased leptin levels and increasing ghrelin, resulting in increased appetite leading to weight gain.[62] The mechanisms linking SW with overweight/obesity are shown in Figure 6. Naps taken before and during night shifts have been shown to yield beneficial effects on sleepiness and fatigue. The hypothesis that napping during night shifts could help to decrease melatonin suppression and reduce the possibility of negative consequences has been tested.[63,64] Hence, shift schedules should allow workers sufficient opportunities to sleep during protected intervals between shifts. Alternatively, partial rather than complete arrangement to day-oriented schedules (e.g. day shifts and day off) might yield sufficient positive performance and improve sleep outcomes.

From a nutritional perspective, it has been shown that sleep deprivation could induce physiological adaptations that change the individual nutritional status.[65] Other studies have shown that a short sleep duration seems to not only enhance appetite,[7] but also to generate a preference for fat-containing foods.[66,67] Itani *et al.*[34] reported that a short sleep duration is associated with the onset of obesity. Our findings showed that night-shift workers were more likely to be overweight (RR: 1.24). In view of the fact that SW deregulates sleep and wakefulness, efforts should be made towards either minimizing the unfavourable effects on sleep or managing sleep and naps.

Additionally, eating behaviour might be changed by working schedules, especially when night work is involved,[11] because of a diverse range of biological, social and cultural factors. Also, shift workers experience the most job-related stress,[68] which may act as a potential risk factor for weight gain by affecting eating behaviours and food choices and by establishing barriers to healthy

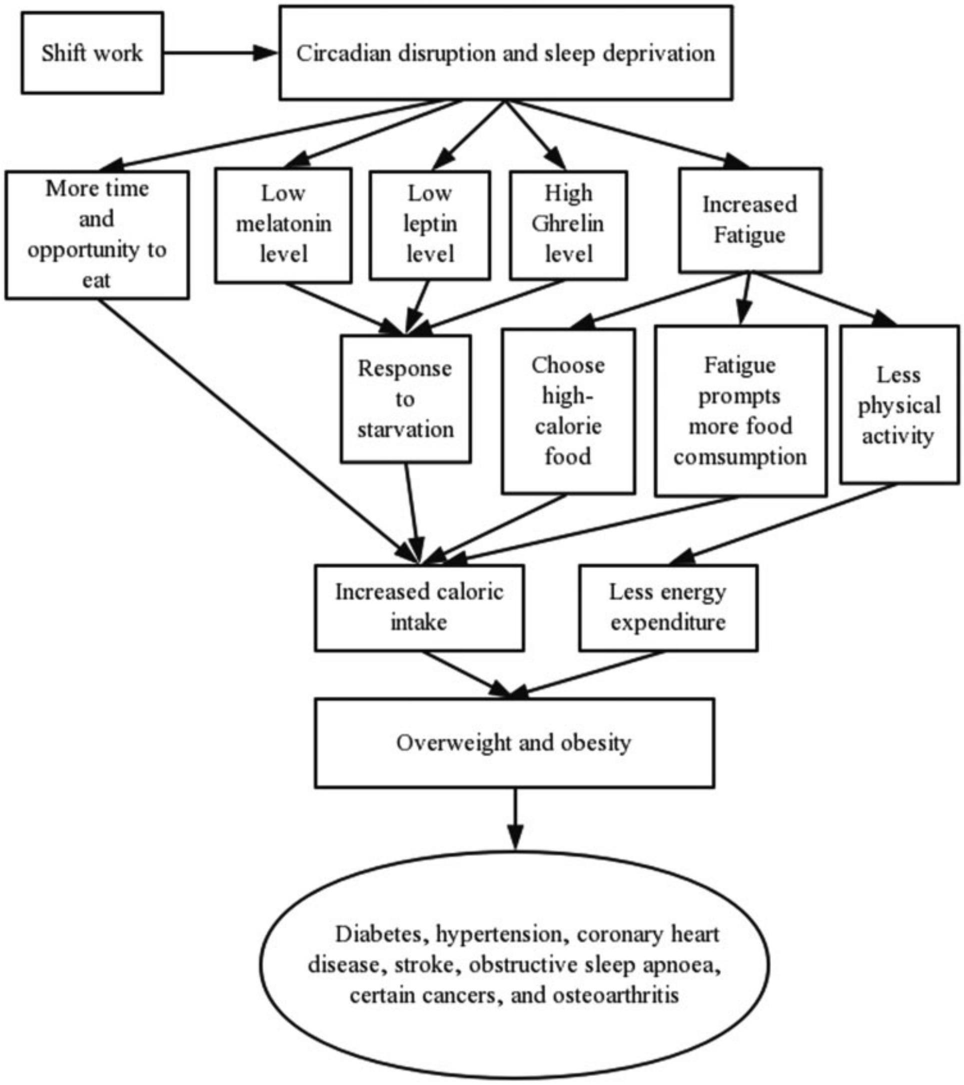

Figure 6. The hypothesized adverse health effects of shift work and potential mechanisms. The risk of overweight/obesity increases with circadian disruption and sleep deprivation in shift workers. Consequently, the likelihood of chronic diseases (e.g. diabetes, hypertension, coronary heart disease, stroke, obstructive sleep apnea, certain cancers and osteoarthritis) increases.

eating.[69] Rotating-shift workers showed a much higher pooled effect on obesity. Rotating shifts involving night work may disturb the circadian rhythm, affect eating habits and reduce physical activities.[21] Coffey *et al.*[70] reported the most job-related stress and fatigue in rotating-shift nurses, which might establish barriers to healthy eating and increase risk of obesity.[69,71] A recent study suggested that shift workers had similar diet quality but higher energy intake compared with day workers.[72] The higher energy intake might be one of the causes of SW-induced overweight, obesity and other adverse health outcomes. Guidance on a healthy eating style is required for this at-risk population group.

Overweight and obesity not only impair work performance, but also increase the morbidity of chronic diseases (e.g. type 2 diabetes mellitus, cancers, hypertension, cardiovascular diseases, osteoarthritis, obstructive sleep apnea).[73] The involvement of both behavioural factors, such as eating late, a calorie-rich diet, sleep deprivation and insufficient physical activity, and intrinsic aspects, including circadian disruption and adipose deregulation, has been identified.[11,74] Many studies have shown that shift workers are more prone to the development of overweight and obesity. Our meta-analysis provided support for a possible association of SW and overweight/obesity. We are aware that these results might be biased on the basis of our searching strategies, initially designed for studying SW and the risk of overweight/obesity. As a relationship between overweight/obesity and risk of chronic diseases has been confirmed, avoiding overweight and obesity is an important strategy in managing risk for chronic diseases.

Strengths and weaknesses

Our study has several strengths. First, it is the largest synthesis of SW and obesity, as well as overweight, reported to date. We have overcome these limitations and provide in-depth analyses of the relationship between SW and overweight/obesity. Second, sensitivity analysis and consistent results from various subgroup analyses indicate that our findings are reliable and robust, although heterogeneity existed among the included studies.

On the other hand, several caveats in our study need to be noted. First, there are several methodological limitations (including overweight/obesity assessment and analytical methodology) worth consideration. Second, due to the limitations of eligible data, the subgroups based on type of SW were crudely classified into day SW, night SW and rotating SW subgroups, regardless of the SW duration, cumulative SW exposure and frequency of SW. Third, high heterogeneity across studies was present for the SW–overweight and SW–obesity links, which throws some doubt on the reliability of the summary RR estimates. However, the results were stable. Fourth, most included studies used the cross-sectional study design, and the relationship between SW and the risk of overweight/obesity might be underestimated for the potential healthy worker survival effect in the cross-sectional studies.[75] Fifth, only studies published in the electronic databases in English and Chinese were reviewed for pertinence, and studies in other languages were omitted. Despite these limitations, the meta-analysis included a substantial number of cohort studies, which greatly strengthened the statistical power of the analysis and provided adequate evidence for the authors to draw a reliable conclusion.

For further studies based on our findings, we suggest that investigations need to improve the standardization of different shift schedules and outcome definitions, which would provide research evidence. Additionally, research should be conducted to confirm our findings and establish the potential biological mechanisms. Finally, more interventional studies are needed to prevent overweight and obesity in the workplace.

Conclusion

In conclusion, the present meta-analysis indicates that SW might be associated with an increased risk of overweight and obesity. Owing to the substantial heterogeneity, further high-quality studies are required to address the existing limitations in the literature. Given the worldwide increasing prevalence of SW and the potential side effects of overweight/obesity on health, the results of our study suggest that both the managers in charge of working time organization and the involved workers must be sufficiently informed about the possible adverse effects of SW. Furthermore, shift schedules should be designed according to ergonomic criteria recommended to be suitable to limit negative effects on health by avoiding or minimizing circadian disruption and accumulation of sleep deficiency.

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