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Review

Dietary Patterns under the Influence of Rotational Shift Work Schedules: A Systematic Review and Meta-Analysis

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ABSTRACT

Workers employed in rotating shift schedules are at a higher metabolic risk compared with those in regular day and fixed shift schedules; however, the contribution of diet is unclear. This systematic review aimed to investigate how rotating shift work schedules affect dietary energy intake and dietary patterns compared with regular day and fixed shift schedules. In addition, intraperson energy intake and dietary pattern comparisons within rotating shift schedules were investigated. Database searches were conducted on MEDLINE, Cochrane, CINAHL, PSYCinfo, EMBASE, and Scopus, in addition to manual search of bibliographic references, to identify articles. Two separate meta-analyses compared dietary intake between day work and rotating shift work schedules and within the rotational shift work group (morning/day and night shifts). Differences in dietary patterns were synthesized narratively. Thirty-one studies ($n = 18{,}196$ participants) were included in the review, and meta-analyses were conducted with 24-hour mean energy intake data from 18 ($n = 16{,}633$ participants) and 7 ($n = 327$ participants) studies, respectively. The average 24-hour energy intake of rotating shift workers was significantly higher than that of workers in regular daytime schedules [weighted mean difference (WMD): 264 kJ; 95% confidence interval (CI): 70, 458 kJ; $P < 0.008$; $I^2 = 63\%$]. However, the mean difference in 24-hour energy intake between morning/day shifts compared with night shifts within rotational shift schedules was not statistically significant (WMD: 101 kJ; 95% CI: −651, 852 kJ; $P = 0.79$; $I^2 = 77\%$). Dietary patterns of rotating shift workers were different from those of day workers, showing irregular and more frequent meals, increased snacking/eating at night, consumption of fewer core foods, and more discretionary foods. This review highlights that dietary intake in rotational shift workers is potentially higher in calories and features different eating patterns as a consequence of rotating shift work schedules. This review was registered at PROSPERO as ID 182507.

Keywords: systematic review, dietary patterns, rotational shift work, energy intake, nutrition

Statement of Significance

The effect of rotating shift work schedules on dietary patterns is not yet fully understood but may be a contributing factor for improving negative health outcomes associated with circadian rhythm disturbances commonly experienced by shift workers. In recent years, more dietary studies on shift working populations have emerged, warranting an updated investigation into what characterizes dietary patterns among rotating shift workers and whether dietary intake is a contributor to the higher incidence of obesity, metabolic syndrome, and metabolic risk observed in rotating shift work populations.

Introduction

Modern work schedules have significantly diversified from the regular 8-h work day and are often dictated by industry or occupation. By definition, shift work is regularly performed outside of the standard 07:00 to 18:00 work hours and can involve fixed shifts such as night work only or rotating shifts [1]. Unlike fixed shifts, rotating shifts regularly rotate around the

Abbreviations used: FFQ, food frequency questionnaire; I^2, *I*-squared test; TDEI, total daily energy intake; WMD, weighted mean difference.

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clock between different shift types with hours of work changing repeatedly [2]. As a workforce, shift workers comprise approximately 25% of the US population [3] and 20% of the European working population [4], and in Australia, 1.4 million or 16% of employees undertake shift work as their main occupation. Rotating shifts are the most common form of shift work in Australia for both women and men (37% and 48%, respectively) [5]. Although many employees choose shift hours for convenience, better remuneration or to provide family child care, meta-analyses have indicated the consequences of shift work are a higher risk of chronic diseases such as cardiovascular disease (OR: 1.22; 95% CI: 1.09, 1.37; $I^2 = 0\%$) [6], diabetes (OR: 1.09; 95% CI: 1.05, 1.12; $P = 0.014$; $I^2 = 40.9\%$) [7], and cancer (RR: 1.23; 95% CI: 1.08, 1.41; $P < 0.001$; $I^2 = 82.7\%$) [8] than that of day work. In addition, some shift work types may be more detrimental, as subgroup analysis by shift work status has shown a higher risk of type 2 diabetes mellitus among workers with rotating, irregular, and night shift schedule types (42%, 6%, and 9% higher risk, respectively) [7]. Irregular and/or poor dietary patterns may in part contribute to these increased disease risks [9,10] because shift workers alter their eating behavior and timing to accommodate shift schedules. Consuming a greater proportion of daily energy intake in the evening has been associated with obesity and metabolic syndrome [11,12] and eating at night is known to affect circadian rhythm and induce changes in metabolism.

Circadian disruption is associated with shift work and is believed to be partly responsible for the disparity of chronic disease in shift workers [13]. Typically, the body's central clock located in the suprachiasmatic nucleus controls metabolism by cycling through a 24-hour period, whereas peripheral clocks located in tissues throughout the body are synchronized to the central clock when external factors (light exposure, physical activity, and food intake) follow diurnal patterns [14]. Circadian processes at night promote sleep and fasting through regulatory hormones such as melatonin and insulin, whereas feeding and activity dominate daytime hours with optimization of metabolic processes for energy expenditure, insulin secretion, and cholesterol and glycogen synthesis occurring during the early part of the day [14,15]. Night time eating and altered sleep times, as are typical of shift workers, disrupt the synchronization of the central and peripheral clocks and impact on hormones affected by mistimed sleep and food intake. The resulting circadian disruption causes impaired glucose control [16] and impaired lipid tolerance [17,18], which are risk factors for metabolic diseases [14]. Furthermore, there is evidence to suggest that dietary patterns of shift workers at night differ from those of day workers, which could also be contributing to the increase in metabolic risk and higher incidence of metabolic syndrome [19] and obesity [13] in shift workers.

By definition, dietary patterns involve the type, quantity, distribution, and frequency of foods eaten within the diet and present a method for food and nutrients to be examined together in association with a disease risk [20–22]. Night shift workers are reported to have more frequent eating occasions overnight with fewer fasting intervals [23], higher intake of saturated fat and discretionary foods [24], higher caffeine consumption [25], and lower intake of vegetables and fruit [26]. Although overall energy intake of shift workers has previously been reported in systematic reviews and meta-analyses to be similar to day workers [24,27,28], limitations have been the small number of studies that focus exclusively on rotating shift workers as a type of shift schedule and an emphasis on rotating "night" shift energy intakes rather than intakes more representative of changing rotating shift schedules. What is less well known is how individual shift schedules, particularly rotating shift work, may influence energy intake and dietary patterns. To date, studies rarely differentiate between work schedule types other than "day shift" or "night shift" and often combine rotating and non-rotating shift schedules in analyses. Hence, the influence of rotating shift schedules on dietary patterns is not well established. This is critical considering rotating shift workers change hours of work from day to night and the association with poorer metabolic health outcomes and eating at night.

Identifying differences in dietary patterns associated with work schedules has the potential to inform workplace policy to improve metabolic health. Currently, national dietary guidelines do not consider how shift work may affect eating behavior, tending to focus on healthy eating per se in overall prevention of chronic disease risk for the general population. A recent review of online dietary advice for shift workers highlighted the inconsistency in advices offered, they were not targeted to specific types of shift work, and they were mostly based on general healthy eating guidance typically more suited to non–shift-working populations [29]. Thus, the aims of our review using the latest evidence are as follows: *1*) to compare total energy intake between day work schedules and rotating shift schedules through a meta-analysis; *2*) to examine how rotating shift work schedules affect dietary patterns compared with day work and fixed shift work; and *3*) to explore intraperson differences in dietary patterns and dietary intake within rotational shift workers on morning, day, or night shifts through a meta-analysis.

Materials and Methods

This systematic literature review was prospectively registered on PROSPERO (ID 182507) and is reported according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) [30]. Updates to PROSPERO protocols were addition of an author (ZED) and an updated search strategy. The PICO (population, intervention/exposure, comparison and outcome) strategy was used to construct research questions for the review (Table 1).

Search strategy

On 11 November 2020, the Ovid MEDLINE, Cochrane, CINAHL, PSYCinfo, EMBASE, and Scopus databases were systematically searched for relevant publications limited to humans and according to the date of database inception. An identical updated search was re-run on 12 April 2022. Search terms were

TABLE 1
PICO strategy

Criteria	Definition
Population	Adult shift workers and regular day workers
Intervention/ exposure	Rotational shift schedules
Comparison	Regular day work, fixed shift work schedules: morning, day, afternoon, evening, and night
Outcomes	Dietary patterns and dietary intake

performed using MeSH headings, title, abstract, and keywords fields and included the following using 2 keyword groups: *1*) work schedules (shift*/work*/schedul*/system*/night/evening/afternoon/extend*/late*/rotat*/irregular/day/early/morning/regular/standard/ordinary/personnel staffing and scheduling (MeSH)/shift work schedule (MeSH)) AND *2*) dietary patterns (meal*/eat*/food*/diet*/energy/snack/calor*/nutr*/intake*/pattern*/habit*/behavio*/frequenc*/episode*/quality*/feeding behaviour (MeSH)/energy intake (MeSH)). In addition, a manual search of bibliographic references used in a previous meta-analysis on energy intake in shift workers compared with regular day workers was conducted.

Inclusion criteria

Studies that met the following inclusion criteria were selected: *1*) peer-reviewed articles in English with full-text availability; *2*) human studies in adults aged older than 18 y; *3*) observational or intervention study designs; *4*) if the study included rotational shift workers as a comparator against regular day workers or fixed shift workers, in relation to quantitative measures of dietary patterns; *5*) if the study reported on either energy intake values (in kilojoules or calories) or quantitative dietary patterns according to rotational shift, fixed shift, and day work schedules; or *6*) if the study included rotational shift workers only but specified and compared energy intake values between shift types (i.e., morning, day, afternoon, evening, or night shifts within a rotating shift schedule). Studies were excluded if inadequate dietary pattern information were provided: for instance, where single foods or nutrients were solely used, or if dietary information was presented within a lifestyle score. If studies did not provide adequate shift schedule descriptions (shift duration, starting and finishing times, or shift type) or did not separate participants on rotating schedules from other shift schedule types for data collection or analysis, these studies were not included. Studies that were not published in English or were in vitro, such as laboratory simulations of shift work conditions, or studies involving industries that experience time zone changes were also excluded. Finally, if studies received a "negative" quality rating, they were excluded.

Study selection

Retrieved articles were first imported into Endnote X9 [31] and transferred to Covidence [32], in which duplicate records were removed and the remaining citations managed for the study selection process. Studies were first screened by title and abstract by duplicate reviewers (ABC, MPB, AMC, ZED). Then, full-text studies were retrieved for remaining studies and screened again in duplicate for inclusion (ABC, MPB, AMC, ZED). Disagreements on study eligibility were resolved by consulting a third reviewer (MPB, AMC, or ZED).

Data extraction

Data from the included studies in Covidence were extracted and tabulated in Microsoft Excel for details on the following: study design and aim; geographical location of study and setting; sample size; work schedule exposure; dietary patterns; dietary assessment tools; total dietary intake including 24-hour energy intake; and results of the analysis and key conclusions. Where studies reported energy intake, dietary assessment methodologies were checked to ensure only studies reporting mean 24-hour energy intake were included in the meta-analysis, such as 24-hour recall, continuous food diaries/records, or food frequency questionnaire (FFQ). Data extraction was conducted by 1 reviewer (ABC) and independently crosschecked by one of the 3 reviewers (MPB, AMC, ZED). Where disagreements occurred between 2 reviewers, a third reviewer was consulted (MPB, AMC, or ZED). Authors were contacted through e-mail where data were collected but not reported [33–38]. If no response was received after a second contact attempt, the study data were not included in the meta-analyses. Three studies containing identical data to other included studies were identified [39–41] and not used in this review.

Quality assessment

The Quality Criteria Checklist for Primary Research sourced from the Academy of Nutrition and Dietetics was used to assess the included studies in duplicate [42]. The tool aims to assess quality of original studies in the area of nutrition and comprises 4 questions to rate applicability (improved outcomes of intervention, relevance to population/clinical practice, and feasibility of interventions), and 10 validity questions for scientific rigor to identify compromised validity in research. Studies were designated overall as "positive," "neutral," or "negative" based on "yes/no/unclear" responses to validity criteria questions 2, 3, 6, and 7. If there was a discrepancy between 2 reviewers, each component was again reviewed to reach a consensus for the final rating of positive (indicating the study controlled issues related to inclusion/exclusion criteria, data collection, bias, generalizability and analysis); neutral (indicating the study is not substantially strong or weak); or negative (signifying a study does not adequately control for issues as described for a "positive" rating). A third reviewer (AMC, MPB, or ZED) was consulted to resolve disagreements.

Statistical methods

Differences in dietary patterns (type, quantity, distribution, and frequency of foods eaten within the diet) according to rotational shift work, fixed shift work and day work schedules were tabulated. For data on dietary patterns, a narrative synthesis was conducted due to heterogeneity reported between the included studies. All reported mean energy intakes were converted to kilojoules (from kilocalories) before the meta-analysis, and a conversion factor of 4.1868 kJ per 1 kcal was used [43]. If SEs or 95% CIs were used in the selected studies, these were converted to SD using the formula $SD = SE \times \sqrt{N}$ and $SD = \sqrt{N} \times (\text{upper limit} - \text{lower limit})/3.92$, respectively [44]. The meta-analysis was conducted on mean and SDs of energy intake using Review Manager [45] so that 24-hour energy intake and weighted mean difference (WMD) comparisons between work schedule groups were summarized quantitatively. If studies involved 2 or more rotating shift schedule groups as a comparator with a permanent morning or day work schedule group [34, 46–48], the latter group sample size was halved and used twice as a control group in the meta-analysis according to Cochrane Handbook guidelines [44]. One study stratified age ranges into 4 groups to compare day workers and rotating shift workers [49], and this stratification was also used in the meta-analysis. Sensitivity analysis was conducted on these multiple entry studies to determine if weighting attributed to the entries influenced results, in addition to studies with significantly larger sample sizes and thus more weighting [50,51] by performing the analysis both with and without these studies. A second meta-analysis was performed to compare differences in intraperson energy intake (WMD) of rotational shift workers when working a day or morning shift compared with that of a night shift. We used a random-effects model for the meta-analysis to consider heterogeneity between studies and calculated WMD in energy intake, 95% CIs and the *I*-squared test (I^2). Heterogeneity was considered low if I^2 values were 25%, moderate if 50%, and high if 75% [52]. A *P* value of <0.05 was considered statistically significant.

Results

After performing the second database search in April 2022, 10,581 studies were identified from which 30 studies were included, with the addition of 1 study identified through manual bibliographic searches of previous systematic reviews [38]. Figure 1 summarizes the selection process for the 31 included studies in this systematic review. Studies that detailed 24-hour energy intake data for the 2 meta-analyses comprised 18 and 7, studies respectively.

Description of included studies

The 31 included studies represented 17 countries, with the greatest number of studies ($n = 15$) conducted in the Asia-Pacific region [33,35,37,38,46,48–51,53–58], 12 from European countries [18,34,47,59–67], 3 from Turkey [36,68,69], and 1 from Israel [70]. Studies were published between 1979 and 2022, and most of them (n = 25) were of cross-sectional design, whereas 6 were observational studies. The predominant occupations represented were from industrial [18,46–49,60,62,64,67] and health care occupations [34,37,46,50,51,53,54,56–59,61,63,66,68–70], followed by first response workers [33,35], hospitality [65], and security personnel [36]; however, 2 studies did not specify participant occupations [38,55]. The characteristics of included studies are detailed in Table 2. Work schedule definitions were not consistently documented; 9 studies did not provide work schedule start and finish times [37,38,49,50,54,56,63,65,68], and 5 studies provided partial work schedule definitions [46,53,55,61,64].

Of the 31 studies ($n = 18{,}196$ participants), 16,960 study participants contributed data to the meta-analyses. Sample sizes of studies included in the analysis ranged from 5 to 6412 participants and were either exclusively female [48,50,51,58,63,69,70] or male participants [36,47,49,60,62,64,67] or combined female and male participants ($n = 11$). One study did not report on the gender distribution of the study participants [57] and another stratified participants by gender [68]. Mean and median ages among study participants ranged from 24 to 55 y. Included studies used a range of dietary assessment methods such as 24-hour dietary recalls, food diaries, food records, FFQs, and food photographs.

Studies were divided into 2 groups according to work schedule comparisons: either comparing rotating shift work and day/fixed shift work schedules ($n = 21$) (Table 3) or intraperson

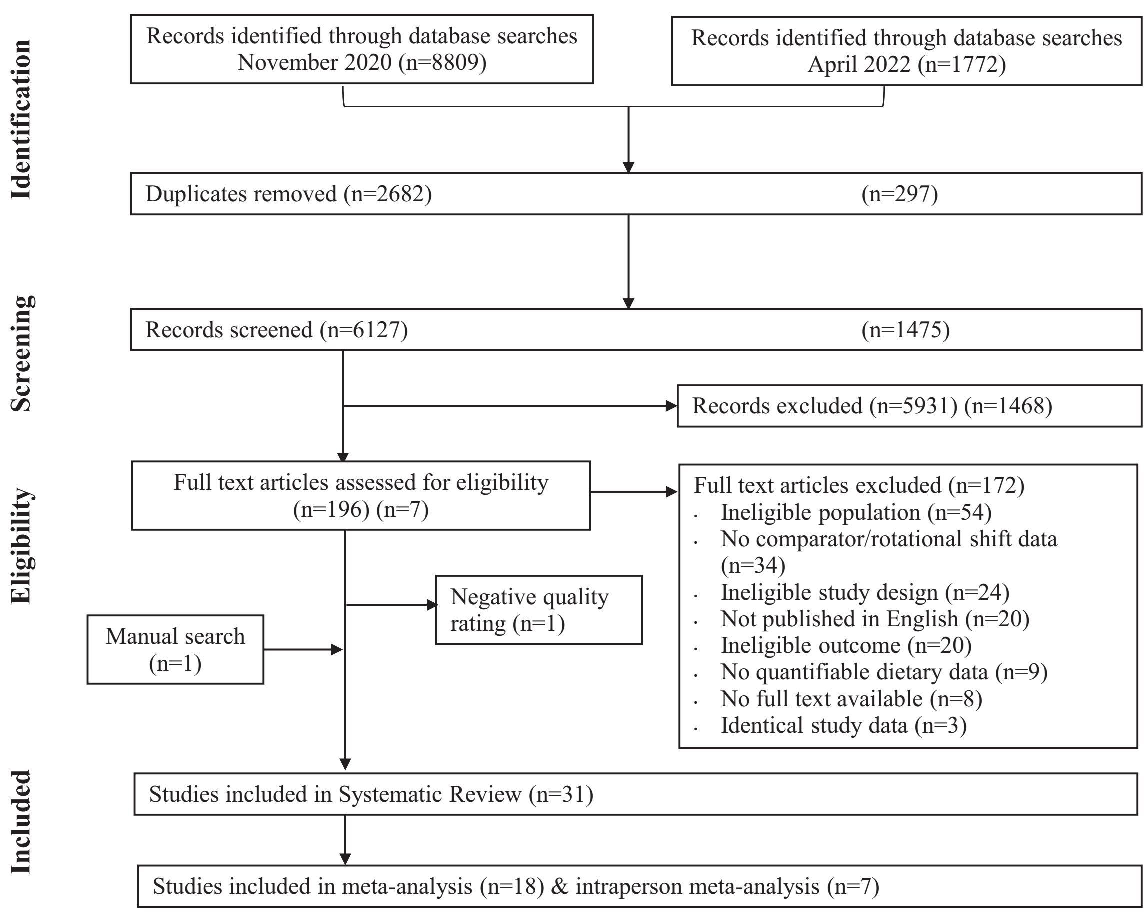

FIGURE 1. PRISMA flowchart for the selection process of the included studies.

TABLE 2
Characteristics of included studies investigating dietary intake and patterns according to day work, shift work, and rotating shift work comparisons

Author [reference], country	Study design	Work type	Work schedule (h)	N (% F)	Age (y)[1]	BMI (kg/m²)[1]	Dietary assessment
Bonnell et al. [33], Australia	CS	Firefighters	Rotating: 07:00–17:00; 17:00–07:00	19 (5)	36 (29, 51)	24.7 (23, 27)	24-h dietary recall (2–4 d)
Bouillon-Minois et al. [59], France	Obs	Emergency health care	Rotating: 08:30–18:30; 18:30–08:30	184 (56)	37.2 ± 10.2	23.2 ± 3.9	24-h dietary recall (2 d)
Chen et al. [37], United States	Obs	Health care	Day[2]	5 (100)	47.4 (30, 64)	27.2 ± 7.3	Food diary app “Fat Secret” (14 d)
			Night[2]	5 (100)	36.8 (22, 67)	28.0 ± 8.7	
			Rotating[2]	4 (50)	49.5 (42, 63)	27.6 ± 4.8	
Esquirol et al. [60], France	CS	Chemical plant	Day: 08:00–16:00	98 (0)	48.8 ± 5.2	26.4 ± 3.3	Self-administered diet history questionnaire (3 d)
			Rotating: 05:00–1300; 13:00–21:00; 21:00–05:00	100 (0)	46.5 ± 4.4	26.3 ± 3.4	
Farias et al. [53], Chile	CS	Hospital health	Day: 08:00–17:00	17 (94)	38.8 ± 14.0	30.7 ± 9.5	24-h dietary recall (1 d) and food history record (1 d)
			Rotating[2]	33 (94)	36.2 ± 12.6	29.0 ± 6.3	
Flanagan et al. [61], United Kingdom	CS	Hospital nurses and midwives	Rotating[2]: 21:00–07:00	20 (100)	42.7 ± 6.5	NR	Food diary (14 d)
Fradkin et al. [70], Israel	CS	Nurses	Rotating: 07:00–15:00; 23:00–07:00	132 (100)	39.6 ± 6.4	Mean/median NR	24-h food diary (2 d)
Han et al. [54], South Korea	CS	Nurses	Fixed day/evening[2]	53 (100)	36.6 ± 4.1	Mean/median NR	Structured questionnaire (dietary intake over 4 wk)
			Rotating with nights[2]	252 (100)	28.8 ± 3.9		
			Rotating without nights[2]	35 (100)	31.2 ± 3.7		
Heath et al. [46], Australia	CS	Printing, postal, nursing, and oil and gas industry	Permanent morning: 07:00–15:30	33 (21)	44.8 ± 9.9	25.8 ± 2.8	FFQ (dietary intake over 1 y)
			Permanent night: 21:00–07:30	27 (37)	42.7 ± 9.9	26.8 ± 5.1	
			8-h rotating: 07:00–15:30; 21:00–07:30	29 (66)	41.2 ± 11.7	27.5 ± 5.5	
			12-h rotating[2]	29 (4)	44.2 ± 7.9	28.3 ± 4.0	
Hulsegge et al. [34], Netherlands[3]	CS	Health care	Day: 08:00–16:30 or 08:30–17:00	78 (83)	47.3 ± 10.8	25.2 ± 4.2	Food diary (2–3 d)
			Rotating: 07:30–16:00; 15:00–23:00; 23:00–07:30	407 (90)	40.8 ± 11.9	25.0 ± 4.0	
Kosmadopoulos et al. [35], Canada	Obs	Police officers	Rotating: 07:00–16:00; 07:00–19:00; 15:00–24:00; 19:00–07:00; 22:30–07:30; 23:00–08:00	31 (19)	32.1 ± 5.4	25.0 ± 2.3	Food/meal type photographs and food charts (3–4 d)
Lennernas et al. [47], Sweden	CS	Industrial	Day: 06:54–15:30	37 (0)	40.9 ± 6.1	24.3 ± 3.0	24-h dietary recall (2–4 d)
			Rotating: 2-shift, 05:30–14:00; 14:00–22:30	34 (0)	40.8 ± 7.1	25.5 ± 3.7	
			Rotating: 3-shift; 05:30–14:00; 14:00–22:30; 22:30–05:30	25 (0)	36.1 ± 7.2	25.0 ± 2.4	
Lennernäs et al. [62], Sweden	CS	Papermill	Rotating: 06:00–14:00; 14:00–22:00; 22:00–06:00; 06:00–18:00; 18:00–06:00	16 (0)	34.8 ± 12.0	25.2 ± 2.8	24-h dietary recall (5 d)
Lennernas et al. [18], Sweden	CS	Industrial	Rotating: 05:30–14:00; 14:00–22:30; 22:30–05:30	22 (0)	35.7 ± 7.2	24.5 ± 1.9	24-h dietary recall; (≥4 d)
Manodpitipong et al. [55], Thailand	CS	NR	Day: 06:00–19:00	85 (58)	52.7 ± 9.1	28.6 ± 5.0	24-h dietary recall (1 d)
			Night[2]	60 (50)	47.1 ± 8.9	29.6 ± 6.1	
			Rotating[2]	49 (55)	44.9 ± 7.9	29.9 ± 6.1	
Mansouri et al. [56], United States	Obs	Emergency medical services	Day[2]	19 (42)	30.9 ± 9.2	29.2 ± 5.7	Remote food photography (2 d)
			Night[2]	10 (50)	25.4 ± 3.5	27.4 ± 6.3	
			Rotating[2]	7 (43)	28.9 ± 8.7	28.0 ± 5.8	
Morikawa et al. [49], Japan	CS	Factory	Day[2]	167 (0)	20–29 y: 25.2 ± 2.9	22.3 ± 2.9	FFQ (dietary intake over 1 mo)
				235 (0)	30–39 y: 34.6 ± 2.9	22.7 ± 2.7	
				284 (0)	40–49 y: 44.7 ± 2.6	23.4 ± 3.0	
				519 (0)	50–59 y: 54.3 ± 2.7	23.0 ± 2.6	
			Rotating without midnight shift[2]	80 (0)	20–29 y: 24.4 ± 2.9	22.7 ± 4.7	

(continued on next page)

TABLE 2 (*continued*)

Author [reference], country	Study design	Work type	Work schedule (h)	*N* (% F)	Age (y)[1]	BMI (kg/m^2)[1]	Dietary assessment
				53 (0)	30–39 y: 34.3 ± 2.8	24.3 ± 3.4	
				92 (0)	40–49 y: 44.5 ± 2.8	23.8 ± 3.2	
				101 (0)	50–59 y: 54.2 ± 2.5	23.4 ± 2.9	
			Rotating with midnight shift[2]	161 (0)	20–29 y: 25.1 ± 2.8	22.4 ± 3.3	
				155 (0)	30–39 y: 34.1 ± 2.9	23.2 ± 3.5	
				175 (0)	40–49 y: 44.5 ± 2.7	23.7 ± 3.0	
				132 (0)	50–59 y: 54.1 ± 2.7	23.0 ± 2.9	
Mortaş et al. [36], Turkey	Obs	Security officers	Rotating: 07:00–15:00; 23:00–07:00	10 (0)	Range, 25–40	24.9 ± 3.2	Dietary records (7 d)
Peplonska et al. [63], Poland	CS	Nurses and midwives	Day[2]	271 (100)	55.1 ± 5.2	Mean/ median NR	FFQ (dietary intake over 1 y)
			Rotating[2]	251 (100)	53.1 ± 5.0		
Reinberg et al. [67], France	Obs	Oil refinery research unit	Rotating: 07:45–16:30; 21:00–06:00; 06:00–13:00; 13:00–21:00	5 (0)	Range, 21–36	23.7 (SD: NR)	Self-recorded food sheets (daily intake over 8 wk)
Romon et al. [64], France	CS	Chemical plant/ nuclear power station	Day[2]	70 (0)	32.4 ± 19.2	24.7 ± 8.2	Food record (3 d)
			Rotating: 06:00–14:00; 14:00–22:00; 22:00–06:00	71 (0)	31.9 ± 19.8	24.6 ± 13.9	
Sathyanarayana and Gangadharaiah [57], India	CS	Doctors, nurses, technicians and support	Day 08:00–17:00	20 (% NR)	34.3 ± 8.2	27.5 ± 5.1	24-h dietary recall (1 d)
			Rotating: 08:00–17:00; 20:00–08:00	20 (% NR)	27.5 ± 5.2	20.4 ± 1.0	
Seibt et al. [65], Germany	CS	Hotel	Day[2]	97 (68)	35.0 ± 10.2	24.8 ± 4.3	FFQ (timeframe NR)
			Rotating[2]	53 (45)	33.7 ± 9.5	24.3 ± 3.4	
Seychell and Reeves [66], Malta	CS	Nurses	Day: 07:00–19:00	29 (69)	35.8 ± 11.7	25.6 ± 5.2	FFQ (timeframe NR)
			Night: 19:00–07:00	13 (77)	40.2 ± 10.5	27.0 ± 3.1	
			Rotating: 07:00–19:00; 19:00–07:00	68 (72)	26.7 ± 4.7	26.4 ± 5.0	
Sudo and Ohtsuka [48], Japan	CS	Computer manufacturing	Day: 08:30–17:15	44 (100)	28 (25, 31)	20.2 (19, 21)	Food records and photographic dietary assessment (3 d)
			Early-shift rotating: 06:00–13:45	47 (100)	26 (24, 29)	21.3 (20, 23)	
			Late-shift rotating: 13:40–22:25	46 (100)	25 (20, 28)	22.1 (20, 25)	
Tada et al. [50], Japan	CS	Nurses	Day[2]	1179 (100)	42.1 ± 10.2	21.2 ± 2.7	FFQ (dietary intake over 1 mo)
			Rotating[2]	1579 (100)	41.1 ± 11.1	21.6 ± 3.2	
Ulusoy et al. [68], Turkey	CS	Nurses	Rotating[2]	44 (73)	24.5 ± 5.3	22.9 ± 3.6	24-h dietary recall (7 d)
Varli and Bilici [69], Turkey	CS	Nurses	Day: 08:00–16:00	54 (100)	33.0 ± 6.3	24.7 ± 3.5	24-h dietary recall (3 d)
			Rotating: 08:00–16:00; 16:00–0800	56 (100)	(combined)	23.8 ± 3.4	
Wirth et al. [38], United States[3]	CS	NR	Day[2]	6412 (NR)	NR	28.5 ± 10.4	24-h dietary recall (1 d)
			Night[2]	381 (NR)		29.1 ± 7.2	
			Rotating[2]	681 (NR)		28.6 ± 9.7	
Yoshizaki et al. [58], Japan	CS	Aged care workers and caregivers	Day: 09:00–18:00	14 (100)	38.0 ± 8.9	22.6 ± 3.4	Dietary records (1 d)
			Rotating: 09:00–18:00; 18:00–09:00	13 (100)	41.2 ± 11.9	22.5 ± 2.6	
Yoshizaki et al. [51], Japan	CS	Nurses	Day: 09:00–18:00	1095 (100)	41.2 ± 9.4	21.2 ± 2.7	FFQ (dietary intake over 1 mo)
			Rotating: 09:00–18:00; 18:00–09:00; 16:30–01:00; 00:45–09:15	1464 (100)	40.3 ± 10.3	21.6 ± 3.2	

CS, cross-sectional; F, female; FFQ, food frequency questionnaire; NR, not reported; Obs, observational.
[1] Values are mean or median (IQR).
[2] Shift not defined/partially defined.
[3] Additional data provided by authors per request.

comparisons between rotating shift schedule types within a rotating work cycle (morning, day, afternoon, evening, or night shifts) (n = 10) (Table 4). Afterward, studies were compared according to outcomes of total energy and macronutrient intake and dietary patterns to determine the effect of work schedule or shift type on these dietary parameters.

Rotating shift work and regular daytime work schedule comparisons

Table 3 summarizes the main results for the first group comparison of 21 studies comparing total energy, macronutrient, and dietary pattern intakes of regular day/morning workers with those of rotating and other shift workers [34,37,38,46–51,53–58,60,63–66,69]. The data for 6302 rotating shift workers, 10,829 regular day workers, 496 night shift workers, 53 fixed day/evening shift workers, and 33 permanent morning workers was narratively synthesized from the 21 studies.

Energy and macronutrient comparisons

The meta-analysis of 24-hour energy intake comparing regular day/morning schedules and rotating shift schedules from 18 of the 21 studies is shown in Figure 2. Three studies were excluded from the meta-analysis for either not including dietary intake data [54,65] or not being able to provide 24-hour mean energy intake data from median values at the time of request [37]. In total, 29 study/subgroup comparisons were made from the 18 included studies. The WMD in 24-hour energy intake was significantly higher for rotating shift schedules than that for regular daytime schedules (WMD: 264 kJ; 95% CI: 70, 458 kJ; $P = 0.008$; $I^2 = 63\%$). A sensitivity analysis was conducted without the 2 largest studies [50,51] which resulted in a higher WMD in energy of 317 kJ in rotating shift schedules than that of day/-morning schedules (95% CI: 70, 567 kJ; $P = 0.01$; $I^2 = 60\%$) (Supplemental Figure 1). When multiple entry studies were tested for sensitivity [34,46–49], WMD remained statistically significant and favored higher energy intake in the rotating shift work group compared with regular daytime schedules (WMD: 270 kJ; 95% CI: 19, 523 kJ; $P = 0.04$; $I^2 = 69\%$) (Supplemental Figure 2). Nineteen of the 21 studies detailed in Table 3 explored energy intake (1 study used median values), and of these, 7 reported significant differences in energy according to work schedule types [37,48,49,55,56,63,66]; however, 4 studies did not conduct tests of significance specifically for rotating shift groups [38,55,56,66].

Sixteen studies reported on macronutrient intakes, 7 of which observed significant differences in macronutrients for protein [48,50,51,66], total fat [48,56,63,66], or carbohydrate [48,53,63] intakes for rotating shift schedules compared with those for regular day work, whereas the remaining studies indicated similar intakes. Three studies indicated significantly lower protein intakes in rotating shift workers than those in day workers [48,50,51], whereas 1 study reported rotating workers consumed more protein than day workers [66]. According to 3 studies, total fat intakes were higher in rotating [63] and night shift workers [56] or both [66], than those in day workers, whereas another study indicated lower fat intakes in rotating shift schedules than those in day work schedules [48]. Three studies observed differences in carbohydrate intake between work schedules: 2 studies reported significantly higher intake in day workers than that in rotating workers [48,53], whereas 1 study found carbohydrate intake to be higher in rotating night shift workers [63].

Dietary pattern comparisons: food type/quantity

As reported in Table 3, 6 of the 21 studies investigated dietary patterns related to food type/quantity among which, 4 studies reported significant differences [49–51,54]. One study found a lower proportion (54%) of the rotating workers (with nights) consumed fruit daily than that of the rotating (without nights) group (77%) and fixed (no night) group (62%) [54]. The same study also reported nonsignificant differences of a greater proportion of rotating workers (with nights) having fried food every second day (59%) and fatty food every 3 d (44%) than that of the 2 other work schedule groups (fixed no-night group 51% and 40% respectively; rotating without-night group 46% and 31%. respectively) [54]. A second study compared food group intakes between day, rotating (no midnight shift), and rotating (with midnight shift) workers, stratified by age [49]. There were significant differences in meat, dairy, vegetable, and fat/oil intakes; rotating shift workers aged 20–29 y with midnight shifts consumed significantly lower dairy, meat, and vegetable intake than both day workers and rotating shift workers without midnight shifts [49]. Similarly, workers with midnight shifts aged 40–49 y consumed less meat in addition to less fat/oils, and workers with midnight shifts aged 50–59 y reported lower intake of vegetables than workers of the other 2 work schedules [49]. The last 2 studies with significant findings were conducted in Japan and found that rotating shift workers consumed less core foods (potatoes/starches, vegetables, fruit, algae, fish/shellfish, and meat) compared with day workers and consumed higher confectionery, alcoholic drinks, and sugar-sweetened beverages [50,51].

Dietary pattern comparisons: food distribution/frequency

Six studies examined dietary patterns concerning distribution/frequency of meals/snacks or percentage of total daily energy intake (%TDEI) by meal type as detailed in Table 3. Of these studies, 4 found significant differences in dietary patterns [34,54,60,69], whereas 2 studies reported no difference. Of the significant findings, rotating shift workers consumed more meals per day than day workers [60] and day workers had more of their energy distributed toward breakfast and lunch (first half of the day), whereas the rotating group redistributed a higher proportion of total daily energy intake to the second light meal and third light meal (second half of the day) [60]. The second study reported significant differences in higher percentage of rotating (with night) shift workers having irregular meals (87%) and snacking at night (44%) than fixed (no night) workers (38%, 6%) and rotating (without night) workers (67%, 26%) [54]. Fewer rotating (with night) shift workers consumed 3 meals a day than the other 2 groups (21%, 40%, and 55%, respectively) [54], which agrees with a third study finding total number of main meals per day was significantly higher in day workers [69].

The fourth study reported that female rotating workers reported significantly more eating episodes than their day worker counterparts but this was not significant among male workers, nor were there any significant differences in the number of snacks or meals per day when these 2 meal types were treated separately [34].

TABLE 3
Summary of main results for energy intake, macronutrient intake, and dietary patterns during rotating shift work compared with day and fixed shift work schedules

Author [reference]	Shift	*N*	Energy intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/ quantity[1]	Distribution/ frequency meals/snacks[1]	
Chen et al. [37]	Day	5	5069 (2307)*	NR	NR	NR	NR	NR	Energy, $P = 0.0373$
	Night	5	4840 (1803)*	NR	NR	NR	NR	NR	
	Rotating	4	4269 (1696)*	NR	NR	NR	NR	NR	
Esquirol et al. [60] [3,4]	Day	98	9362 ± 1720	95.7 ± 21.0	219 ± 58.0	103.6 ± 25.0	NR	4.69 ± 1.0* meals/d (n) 13.85 ± 8.2* breakfast[3] 1.13 ± 2.6 first light meal[3] 41.18 ± 7.5* lunch[3] 2.32 ± 3.4* second light meal[3] 38.63 ± 8.4 dinner[3] 0.38 ± 1.0 third light meal[3]	Meals/d, $P < 0.001$ Breakfast[3], $P < 0.001$ Lunch[3], $P = 0.008$ Second light meal[3], $P = 0.03$ Third light meal[3], $P < 0.0001$
	Rotating	100	9797 ± 2005	90.9 ± 17.8	214 ± 53.5	97.6 ± 22.8	NR	5.19 ± 0.8* meals/d (n) 9.95 ± 7.0* breakfast[3] 1.2 ± 2.6 first light meal[3] 38.3 ± 7.3* lunch[3] 3.48 ± 4.2* second light meal[3] 39.97 ± 7.3 dinner[3] 3.84 ± 4.4* third light meal[3]	
Farias et al. [53] [4]	Day	17	10,444 ± 4673	75.5 ± 29.3	372.3 ± 198.3*	78.3 ± 40.0	2351.5 ± 1089.7 foods/drinks (g/d)	Data NR	CHO, $P = 0.05$
	Rotating	33	8548 ± 2675	78.5 ± 26.4	263.9 ± 91.3*	74.6 ± 36.8	2151.1 ± 684.2 foods/drinks (g/d)	Data NR	
Han et al. [54]	Fixed no night	53	NR	NR	NR	NR	≥1 serving dairy/d 55% Protein (e.g., meat, fish, egg, and tofu) ≥ 3/d 59% Veg every meal 68% ≥1 serving fruit/d 62%* Fried food ≥1 every other day 51% Fatty food ≥1 per 3 d 40% CHO snacks daily 15% salt/soy sauce added 17%	Irregular meals 38%* 1–2 meals/d 36%* 3 meals/d 55%* Irregular 9%* Snack morning 11%* Snack afternoon 49%* Snack evening 30%* Snack night 6%*	Irregular meals, $P < 0.01$ Frequency of meals, $P < 0.01$ Time of snacking, $P < 0.01$ ≥1 servings of fruit/d, $P = 0.03$

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TABLE 3 (*continued*)

Author [reference]	Shift	*N*	Energy intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns: Food type/quantity[1]	Dietary patterns: Distribution/frequency meals/snacks[1]	Reported significance
	Rotating with nights	252	NR	NR	NR	NR	≥1 serving dairy/d 57% Protein (e.g., meat, fish, egg, tofu) ≥3/d 51% Veg every meal 56% ≥1 serving fruit/d 54%* Fried food ≥1 every other day 59% Fatty food ≥1 per 3 d 44% CHO snacks daily 19% Salt/soy sauce added 33%	Irregular meals 87%* 1–2 meals/d 56%* 3 meals/d 21%* Irregular 23%* Snack morning 4%* Snack afternoon 24%* Snack evening 23%* Snack night 44%*	
	Rotating without nights	35	NR	NR	NR	NR	≥1 serving dairy/d 77% Protein (e.g., meat, fish, egg, tofu) ≥3/d 57% Veg every meal 66% ≥1 serving fruit/d 77%* Fried food ≥1 every other day 46% Fatty food ≥1 per 3 d 31% CHO snacks daily 14% Salt/soy sauce added 29%	Irregular meals 67%* 1–2 meals/d 46%* 3 meals/d 40%* Irregular 14%* Snack morning 6%* Snack afternoon 43%* Snack evening 26%* Snack night 26%*	
Heath et al. [46] [3,4]	Morning	33	7954 ± 2979	89.4 ± 34.3 (33%[3])	196.5 ± 81.2 (19%[3])	71.0 ± 28.8 (13%[3])	NR	NR	NS
	Night	27	8816 ± 3616	99.9 ± 43.4 (36%[3])	211.2 ± 86.5 (19%[3])	85.8 ± 38.9 (16%[3])	NR	NR	
	8h rotating	29	8530 ± 3080	101.9 ± 37.6 (34%[3])	208.5 ± 87.3 (21%[3])	79.9 ± 34.1 (14%[3])	NR	NR	
	12h rotating	29	9318 ± 2852	105.5 ± 33.0 (35%[3])	213.3 ± 78.8 (20%[3])	87.2 ± 30.5 (14%[3])	NR	NR	
Hulsegge et al. [34] [2,4]	Day F	58	7200 ± 1210	70.2 ± 12.8	193.5 ± 46.3	65.0 ± 17.0	NR	5.7 (4.9, 6.7) eating episodes/d	Female eating episodes/d, $P<0.05$ (not shown)
	Day M	11	8570 ± 2780	86.4 ± 25.7	234.2 ± 77.4	69.8 ± 26.1	NR	3.0 (2.2, 4.1) snacks/d 2.3 (2.0, 3.0) meals/d	
	Rotating F	198	7457 ± 1700	71.6 ± 18.4	196.9 ± 51.8	69.1 ± 21.2	NR	6.0 (5.0, 6.7) eating episodes/d	
	Rotating M	33	8725 ± 2035	84.3 ± 22.2	232.8 ± 59.7	75.3 ± 22.8	NR	3.3 (2.3, 4.3) snacks/d 2.7 (2.0, 3.0) meals/d	

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TABLE 3 (*continued*)

Author [reference]	Shift	*N*	Energy intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/ quantity[1]	Distribution/ frequency meals/snacks[1]	
Lennernas et al. [47] [4]	Day	37	11,100 ± 3000	91 ± 23	309 ± 84	110 ± 39	NR	NR	NS
	2-shift	34	12,000 ± 3200	96 ± 25	337 ± 102	122 ± 39	NR	NR	
	3-shift	25	11,900 ± 3200	103 ± 25	322 ± 88	118 ± 34	NR	NR	
Manodpitipong et al. [55] [3,4]	Day	85	4706 ± 1708*	43.7 ± 1.7 (16%[3])	161.7 ± 15.4 (58%[3])	32.7 ± 2.6 (26%[3])	NR	NR	Energy, $P < 0.001$
	Night	60	6004 ± 2445*	52.3 ± 2.3 (15%[3])	205.5 ± 16.6 (58%[3])	43.3 ± 3.1 (27%[3])	NR	NR	
	Non-rotating	11	5003 ± 2307	48.0 ± 1.7 (16%[3])	169.8 ± 8.0 (58%[3])	35.0 ± 2.1 (26%[3])	NR	NR	
	Rotating	49	6226 ± 2441	53.1 ± 2.4 (15%[3])	213.5 ± 18.4 (58%[3])	45.3 ± 3.3 (27%[3])	NR	NR	
Mansouri et al. [56] [4]	Day	19	6171 ± 2351*	54.6 ± 21.8 (15%[3])	176.2 ± 89.4 (48%[3])	57.2 ± 32.7* (36%[3])	NR	NR	Energy, $P = 0.037$ Fat, $P = 0.043$
	Night	10	8314 ± 3158*	69.5 ± 28.8 (15%[3])	199.6 ± 101.8 (40%[3])	89.0 ± 34.5* (41%[3])	NR	NR	
	Rotating	7	7691 ± 2815	68.5 ± 24.1 (%[3] NR)	200.4 ± 102.7 (%[3] NR)	79.8 ± 30.7 (%[3] NR)	NR	NR	
Morikawa et al. [49] [3,4]	Day								
	20–29 y	167	8658 ± 2546	11.0 ± 2.0[3]	60.6 ± 7.8[3]	23.6 ± 6.6[3]	20–29 y Meat[5] 25.7 ± 1.8*	NR	30–39 y Energy, $P = 0.004$
	30–39 y	235	8914 ± 2554*	11.1 ± 1.9[3]	59.2 ± 8.0[3]	22.4 ± 5.8[3]	20–29 y Dairy[5] 27.2 ± 3.2*		50–59 y Energy, $P = 0.024$
	40–49 y	284	9140 ± 2784	10.7 ± 2.1[3]	59.0 ± 8.9[3]	20.6 ± 6.8[3]	20–29 y Veg[5] 31.9 ± 2.2*		20–29 y Meat, $P = 0.054$
	50–59 y	519	8830 ± 2529*	11.3 ± 2.2[3]	60.4 ± 8.6[3]	19.1 ± 6.1[3]	40–49 y Meat[5] 15.8 ± 2.1* 40–49 y Fat/oil[5] 8.1 ± 1.7* 50–59 y Veg[5] 35.2 ± 2.1*		20–29 y Dairy, $P = 0.003$ 20–29 y Veg, $P = 0.056$ 40–49 y Meat, $P = 0.008$
	Rotating no midnight shift								
	20–29 y	80	9337 ± 3278	11.4 ± 2.0[3]	60.2 ± 8.7[3]	24.0 ± 7.2[3]	20–29 y Meat[5] 25.8 ± 2.1*	NR	40–49 y Fat/oil, $P = 0.021$
	30–39 y	53	9136 ± 2625	11.0 ± 2.1[3]	58.1 ± 9.6[3]	24.1 ± 7.9[3]	20–29 y Dairy[5] 31.0 ± 3.2*		50–59 y Veg, $P = 0.056$
	40–49 y	92	9182 ± 2252	11.1 ± 1.7[3]	60.1 ± 8.0[3]	20.3 ± 5.7[3]	20–29 y Veg[5] 27.7 ± 2.7*		
	50–59 y	101	9131 ± 3014	11.5 ± 2.4[3]	60.1 ± 9.1[3]	18.7 ± 6.6[3]	40–49 y Meat[55] 18.9 ± 1.8* 40–49 y Fat/oil[5] 7.7 ± 1.6* 50–59 y Veg[5] 31.8 ± 1.9*		
	Rotating with midnight shift								
	20–29 y	161	8780 ± 2981	10.8 ± 2.0[3]	61.1 ± 8.7[3]	22.5 ± 7.2[3]	20–29 y Meat[5] 21.6 ± 2.1*	NR	
	30–39 y	155	9864 ± 3270*	11.0 ± 1.9[3]	58.4 ± 8.1[3]	22.9 ± 7.0[3]	20–29 y Dairy[5] 18.5 ± 3.6*		
	40–49 y	175	9692 ± 3479	10.6 ± 2.1[3]	60.7 ± 8.7[3]	19.4 ± 6.2[3]	20–29 y Veg[5] 25.0 ± 2.5*		
	50–59 y	132	9529 ± 3035*	11.2 ± 2.2[3]	60.9 ± 8.9[3]	18.3 ± 6.3[3]	40–49 y Meat[5] 13.7 ± 2.2*		

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TABLE 3 (*continued*)

Author [reference]	Shift	*N*	Energy intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/ quantity[1]	Distribution/ frequency meals/snacks[1]	
							40–49 y Fat/oil[5] 7.0 ± 1.7* 50–59 y Veg[5] 30.0 ± 1.9*		
Peplonska et al. [63] [4]	Day	271	7758 ± 2427*	74.9 ± 21.7	244 ± 84.5*	70.4 ± 24.5*	NR	NR	Energy, $P = 0.003$ CHO, $P = 0.004$ Fat, $P = 0.001$
	Rotating	251	8424 ± 2639*	75.9 ± 23.4	267 ± 100.3*	78.1 ± 29.3*	NR	NR	
Romon et al. [64] [4]	Day	70	10,748 ± 22,405	94 ± 193	247 ± 663	109 ± 260	NR	NR	NS
	Rotating	71	10,316 ± 21,644	96 ± 211	247 ± 684	104 ± 262	NR	NR	
Sathyanarayana and Gangadharaiah [57] [4]	Day	20	6602 ± 836	NR	NR	NR	NR	NR	NS
	Rotating	20	6658 ± 1297	NR	NR	NR	NR	NR	
Seibt et al. [65]	Day	97	NR	NR	NR	NR	Cereal 6.2 ± 1.8 points (5–7 good)	Breakfast never 11% Breakfast 1–2/wk 21%	NS
							Dairy 10.2 ± 4.4 points (10–15 sufficient)	Breakfast ≥2/wk 8% Breakfast daily 60%	
							Animal products 15.2 ± 3.1 points (10–15 good)	Lunch never 7% Lunch 1–2/wk 7%	
							Fruit/veg 5.5 ± 2.1 points (3–6 good)	Lunch >2/wk 25% Lunch daily 61%	
							Fats 12.2 ± 3.2 points (12–18 optimal)	Dinner never 1% Dinner 1–2/wk 6%	
							Sweets 4.2 ± 4.6 points (0–4 optimal; 5–7 acceptable)	Dinner >2/wk 28% Dinner daily 65% Between meals never 8%	
							Drinks 44.9 ± 8.2 points (26–50 acceptable)	Between meals 1–2/wk 34% Between meals >2/wk 27% Between meals daily 31%	
	Rotating	53	NR	NR	NR	NR	Cereal 5.7 ± 1.7 points (5–7 good)	Breakfast never 23% Breakfast 1–2/wk 15%	
							Dairy 11.5 ± 5.3 points (10–15 sufficient)	Breakfast >2/wk 17% Breakfast daily 45%	
							Animal products 14.3 ± 3.8 points (10–15 good)	Lunch never 2% Lunch 1–2/wk 11%	
							Fruit/veg 5.2 ± 2.4 points (3–6 good)	Lunch >2/wk 28% Lunch daily 59%	

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TABLE 3 (*continued*)

Author [reference]	Shift	*N*	Energy intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/ quantity[1]	Distribution/ frequency meals/snacks[1]	
							Fats 11.8 ± 2.8 points (9–11 good; 12–18 optimal)	Dinner never 0% Dinner 1–2/wk 13% Dinner >2/wk 30%	
							Sweets 3.8 ± 3.4 points (0–4 optimal)	Dinner daily 57% Between meals never 11%	
							Drinks 43.8 ± 8.0 points (26–50 acceptable)	Between meals 1–2/wk 21% Between meals >2/wk 19% Between meals daily 49%	
Seychell and Reeves [66] [4]	Day	29	7210 ± 2035*	95.4 ± 29.9*	186.4 ± 56.9	66.2 ± 21.7*	NR	NR	Energy, $P = 0.04$ Fat, $P = 0.047$ Protein, $P = 0.04$
	Night	13	8219 ± 2119*	114.6 ± 17.9*	210.4 ± 64.9	77.1 ± 26.7*	NR	NR	
	Rotating	68	8646 ± 2742*	113.3 ± 24.1*	221.8 ± 70.4	82.2 ± 32.2*	NR	NR	
Sudo and Ohtsuka [48] [4]	Day	44	8185 ± 1641*	71.2 ± 17.9*	277.5 (241, 310)*	58.0 (43, 68)*	NR	NS	Energy, $P < 0.05$ Protein, $P < 0.05$ CHO, $P < 0.017$ Fat, $P < 0.017$
	Early Rotating	47	7121 ± 1784*	60.0 ± 60.7*	238.0 (195, 281)*	46.8 (38, 60)*	NR	NS	
	Late Rotating	46	6448 ± 2633*	54.2 ± 17.8*	200.0 (164, 262)*	37.2 (29, 52)*	NR	NS	
Tada et al. [50] [4]	Day	1179	7704 ± 2022	62.7 ± 10.6*	233.3 ± 32.2	66.6 ± 11.5	Cereals 315.9 ± 128.4 Potato/starches 33.0 ± 27.1* Pulses 57.9 ± 42.4 Nuts/seeds 2.6 ± 2.9 Green/yellow veg 71.4 ± 39.4* White veg 118.0 ± 64.1* Fruit 73.3 ± 63.9* Algae 12.5 ± 3.8* Fish/shellfish 61.5 ± 39.0* Meat 87.6 ± 43.1* Egg 23.6 ± 15.4 Dairy 122.5 ± 89.8 Fats/oils 12.4 ± 5.6 Confectionery 89.9 ± 47.3* Alcoholic drinks 66.3 ± 109.3* Sugar-sweetened drinks 52.2 ± 90.8*	NR	Protein, $P < 0.001$ Potato/starches, $P < 0.001$ Green/yellow veg, $P < 0.001$ White veg, $P < 0.001$ Fruits, $P < 0.001$ Algae, $P < 0.001$ Fish/shellfish, $P = 0.026$ Meat, $P = 0.015$ Confectionery, $P < 0.001$ Alcoholic drinks, $P = 0.010$ Sugar-sweetened drinks, $P < 0.001$
	Rotating	1579	7670 ± 2102	61.2 ± 10.3*	234.3 ± 31.0	66.2 ± 10.7	Cereals 311.2 ± 115.5 Potato/starches 29.0 ± 25.1* Pulses 55.4 ± 39.6	NR	

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TABLE 3 (*continued*)

Author [reference]	Shift	*N*	Energy intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/ quantity[1]	Distribution/ frequency meals/snacks[1]	
							Nuts/seeds 2.6 ± 3.1 Green/yellow veg 65.2 ± 38.4* White veg 109.9 ± 61.4* Fruit 65.3 ± 62.9* Algae 11.9 ± 3.4* Fish/shellfish 58.2 ± 37.9* Meat 83.5 ± 42.9* Egg 23.2 ± 14.5 Dairy 116.5 ± 98.7 Fats/oils 12.0 ± 5.7 Confectionery 100.0 ± 48* Alcoholic drinks 77.6 ± 120.7* Sugar-sweetened drinks 75.4 ± 112.3*		
Varli and Bilici [69] [4]	Day	54	7092 ± 1805	59.4 ± 176	185.9 ± 54.7	77.1 ± 22.6	NR	2.8 ± 0.5* meals/d	Meals/d $P < 0.001$
	Rotating	56	7352 ± 2759	57.6 ± 21.6	196.3 ± 85.5	79.5 ± 29.5	NR	2.3 ± 0.5* meals/d	
Wirth et al. [38] [2,4]	Day	6412	9620 ± 6303	88.8 ± 70.5	272.0 ± 163.4	87.4 ± 82.5	NR	NR	NR
	Night	381	9430 ± 4053	82.1 ± 45.3	280.2 ± 159.3	82.8 ± 48.2	NR	NR	
	Rotating	681	9480 ± 3857	86.8 ± 49.8	271.4 ± 122.9	85.0 ± 46.2	NR	NR	
Yoshizaki et al. [58] [3,4]	Day	14	8131 ± 1185	NR	NR	NR	NR	Breakfast 18.2 ± 9.6[3] Lunch 36.7 ± 6.0[3] Dinner 41.4 ± 10.7[3] Snacks 3.7 ± 6.3[3]	NS
	Rotating	13	7834 ± 1763	NR	NR	NR	NR	Breakfast 17.0 ± 9.1[3] Lunch 34.9 ± 15.5[3] Dinner 42.3 ± 17.2[3] Snacks 5.7 ± 6.7[3]	
Yoshizaki et al. [51] [4]	Day	1095	7662 ± 1972	64.0 ± 18.7*	231.6 ± 70.1	65.8 ± 20.4	Cereals 314.0 ± 127.0 Potato/starches 32.9 ± 26.4* Pulses 55.8 ± 38.2 Nuts/seeds 1.9 ± 2.7 Green/yellow veg 68.6 ± 36.6* White veg 114.8 ± 58.9* Fruit 70.8 ± 62.2* Algae 4.3 ± 3.6* Fish/shellfish 60.2 ± 38.2* Meat 88.3 ± 42.2*	NR	Protein, $P = 0.046$ Potato/starches, $P < 0.001$ Green/yellow veg, $P < 0.001$ White veg, $P = 0.002$ Fruit, $P = 0.001$ Algae, $P < 0.001$ Fish/shellfish, $P = 0.012$ Meat, $P = 0.029$ Confectionery/ savory snacks, $P < 0.001$ Alcoholic drinks P

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TABLE 3 (*continued*)

Author [reference]	Shift	*N*	Energy intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/ quantity[1]	Distribution/ frequency meals/snacks[1]	
							Egg 24.0 ± 15.1 Dairy 120.1 ± 89.8 Fats/oils 12.9 ± 5.6 Confectionery/ savory snacks 89.1 ± 46.9* Alcoholic drinks 66.6 ± 111.9* Sugar-sweetened drinks 50.4 ± 87.8*		= 0.028 Sugar-sweetened drinks, $P < 0.001$
	Rotating	1464	7662 ± 2068	62.5 ± 19.9*	232.3 ± 69.3	65.5 ± 21.3	Cereals 309.1 ± 114.5 Potato/starches 28.8 ± 25.2* Pulses 53.8 ± 39.8 Nuts/seeds 2.0 ± 3.1 Green/yellow veg 62.6 ± 37.4* White veg 107.2 ± 60.7* Fruit 62.6 ± 59.3* Algae 3.8 ± 3.3* Fish/shellfish 56.4 ± 37.3* Meat 84.6 ± 42.5* Egg 23.6 ± 14.6 Dairy 115.0 ± 99.4 Fats/oils 12.5 ± 5.6 Confectionery/ savory snacks 99.4 ± 47.8* Alcoholic drinks 76.8 ± 121.2* Sugar-sweetened drinks 76.4 ± 114.0*	NR	

CHO, carbohydrate; F, female; M, male; NR, not reported; NS, not statistically significant; TDEI, percentage total daily energy intake; veg, vegetables.

[1] Values are mean or median (IQR) unless stated otherwise. SD was calculated from standard error (53,55,56,60) and from 95% confidence intervals (63,64).

[2] Additional data provided by authors per request: Hulsegge et al. [34] provided data on a subsample of 69 day workers and 231 rotating workers for energy and macronutrient intakes; Wirth et al. [38] provided data on 6412 day workers, 381 night shift workers, and 681 rotating shift workers for energy and macronutrient intakes; and SE was converted to SD.

[3] Energy and/or macronutrient data reported as %TDEI.

[4] Study included in the meta-analysis.

[5] Food groups measured in grams per 1000 kilocalories.

* Significant difference between 2 or more groups ($P < 0.05$).

Rotating shift work intraperson comparisons

In Table 4, synthesized data from 10 studies conducted on intraperson comparisons of energy, macronutrient intake, and dietary patterns in rotating shift workers are summarized [18,33,35,36,59,61,62,67,68,70] to include 483 rotating shift workers, who collectively worked 375 night shifts, 196 morning shifts, 174 day shifts, 38 afternoon shifts, 22 evening shifts, 20 non–night shifts and sixteen 12-hour shifts during the observation period.

Energy and macronutrient comparisons

A meta-analysis of 7 of the 10 studies exploring intraperson energy intake across different rotating shift types is shown in Figure 3. Three studies were excluded from the meta-analysis because of reporting energy intake during working hours only [61], using percentage of basal metabolic rate for energy intake [35], or using percentage of 24-hour energy intake averaged across a work cycle for energy intake during a work shift [18].

TABLE 4

Summary of main results for intraperson comparison of energy, macronutrient intake, and dietary patterns in rotating shift schedules

Author [reference]	Shift type	*N*	Energy Intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/quantity[1] (g/d)	Distribution/frequency meals/snacks[1]	
Bonnell et al. [33] [2,3]	Day	19	11,709 ± 2298	166.2 ± 40.2	273.5 ± 70.1	101.3 ± 27.6	NR	NR	NS
	Night	19	11,077 ± 3377	144.7 ± 40.7	274.6 ± 83.4	99.0 ± 46.4	NR	NR	
Bouillon-Minois et al. [59] [3]	Day	101	6727 ± 3133*	80.6 ± 30.3*	178.8 ± 81.5	75.1 ± 35.9*	NR	NR	Energy, $P = 0.049$
	Night	83	5863 ± 2966*	66.4 ± 36.4*	163.3 ± 86.0	61.1 ± 32.7*	NR	NR	Fat, $P = 0.030$ Protein, $P < 0.001$
Flanagan et al. [61] [4,5]	Non-nightshift	20	6494 ± 1371[4]	28.9 ± 23.8[5]	38.1 ± 30.2[5]	31.7 ± 29.3[5]	NR	19.7 ± 4.6* Morning[5] 30.5 ± 6.9 Afternoon[5] 46.4 ± 7.5* Evening[5] 8.2 ± 5.2* Night[5]	Morning[5], $P = 0.034$ Evening[5], $P = 0.044$ Night[5], $P = 0.0001$
	Night	20	6559 ± 2333[4]	20.5 ± 17.2[5]	25.4 ± 16.6[5]	23.7 ± 17.2[5]	NR	15.8 ± 9.0* Morning[5] 28.3 ± 13.5 Afternoon[5] 38.8 ± 11.9* Evening[5] 29.8 ± 5.1* Night[5]	
Fradkin et al. [70] [3]	Morning	132	6027 ± 2183*	72.4 ± 33.7	147.3 ± 62.9*	59.4 ± 28.0*	NR	NR	Energy, $P < 0.0001$
	Night	132	6819 ± 2221*	77.9 ± 32.9	171.2 ± 64.4*	68.9 ± 29.5*	NR	NR	CHO, $P < 0.0001$ Fat, $P < 0.0001$
Kosmadopoulos et al. [35] [6]	Morning	21	170.5 ± 51.4*	28.2 ± 9.0	74.5 ± 25.8	62.8 ± 25.9*	NR	6.3 ± 2.1* Meals/d (n)	Energy, $P = 0.001$
	Evening	17	129.6 ± 46.4*	23.7 ± 8.2	59.6 ± 26.8	45.2 ± 19.3*	NR	5.0 ± 1.4* Meals/d (n)	Fat, $P = 0.004$ Meals, $P < 0.001$
	Night	24	142.7 ± 41.6	26.8 ± 9.5	65.4 ± 26.4	50.2 ± 18.8	NR	5.9 ± 1.7* Meals/d (n)	
Lennernas et al. [62] [3]	Morning	16	15,300 ± 3600	126 ± 33*	408 ± 104	168 ± 57	NR	NR	Energy, $P = 0.0339$
	Afternoon	16	15,600 ± 4800	139 ± 42	421 ± 135	164 ± 67	NR	NR	Protein, $P = 0.0436$
	Night	16	14,900 ± 3900*	134 ± 41	387 ± 100	159 ± 45	NR	NR	
	12-h day	16	16,700 ± 4100*	150 ± 42*	449 ± 129	166 ± 53	NR	NR	
Lennernas et al. [18] [7]	Morning	22	5640 ± 959	48.9 ± 7.8	153.2 ± 21.5	55.2 ± 11.6	NR	NR	Energy, $P < 0.001$
	Afternoon	22	6120 ± 979*	49.9 ± 9.0*	172.8 ± 27.6*	57.6 ± 10.4*	NR	NR	Protein, $P < 0.01$ CHO, $P < 0.001$
	Night	22	4200 ± 420*	36.4 ± 3.6*	114.1 ± 12.6*	42.0 ± 5.5*	NR	NR	fat, $P < 0.01$
Mortaş et al. [36] [2,3]	Day	10	9453 ± 1616	69.8 (18)	235.3 (103)	105.9 (38)	NR	NR	NS
	Night	10	8689 ± 2269	63.3 (1)	213.2 (109)	97.9 (52)	NR	NR	
Reinberg et al. [67] [3,8]	Morning	5	8750 ± 467*	21.1 ± 3.1*	51.2 ± 4.2	51.2 ± 4.2	NR	NR	Energy, $P < 0.05$ Protein, $P < 0.05$
	Evening	5	8428 ± 458	17.9 ± 1.3	50.1 ± 4.5	50.1 ± 4.5	NR	NR	
	Night	5	7649 ± 599*	17.5 ± 3.1*	48.5 ± 4.9	48.5 ± 4.9	NR	NR	
Ulusoy et al. [68] [3]	Day F	32	8796 ± 1495*	78.3 ± 14.3*	225.4 ± 45.2*	NR	Dairy 204.7 ± 96.7 Meat 185.2 ± 48.0*	2.9 ± 0.3* Meals/d (n) 1.5 ± 1.2* Snacks/d (n)	F Energy, $P = 0.003$ F Protein, $P = 0.019$

(*continued on next page*)

TABLE 4 (*continued*)

Author [reference]	Shift type	*N*	Energy Intake[1] (kJ/d)	Protein[1] (g/d)	CHO[1] (g/d)	Fat[1] (g/d)	Dietary patterns		Reported significance
							Food type/ quantity[1] (g/d)	Distribution/ frequency meals/ snacks[1]	
							Cereals 220.5 ± 45.9 Veg/fruit 360.7 ± 112.5 Oils/fats 61.2 ± 14.4 Sweets 33.3 ± 24.9*		F CHO, *P* = 0.024 F Meat, *P* < 0.001 M Meat, *P* = 0.005 F Sweets, *P* = 0.002
	Day M	12	10,383 ± 1443	84.4 ± 12.3	281.0 ± 46.1	NR	Dairy 210.5 ± 84.2 Meat 184.1 ± 49.3* Cereals 255.9 ± 48.3 Veg/fruit 326.4 ± 117.4 Oils/fats 68.0 ± 15.8 Sweets 58.9 ± 29.6	2.8 ± 0.5* Meals/d (n) 1.3 ± 1.0 Snacks/d (n)	F Meals, *P* < 0.001 M Meals, *P* = 0.025 F Snacks, *P* = 0.016
	Night F	32	9667 ± 1591*	71.7 ± 9.5*	254.1 ± 55.0*	NR	Dairy 205.9 ± 99.3 Meat 137.0 ± 42.7* Cereals 262.6 ± 74.0 Veg/fruit 308.1 ± 195.5 Oils/fats 58.7 ± 22.3 Sweets 60.0 ± 52.3*	2.3 ± 0.5* Meals/d (n) 1.0 ± 1.2* Snacks/d (n)	
	Night M	12	11,191 ± 2226	82.8 ± 19.2	319.7 ± 61.1	NR	Dairy 181.1 ± 85.9 Meat 162.7 ± 106.0* Cereals 337.9 ± 102.9 Veg/fruit 302.0 ± 158.8 Oils/fats 89.7 ± 107.7 Sweets 71.1 ± 32.3	2.3 ± 0.5* Meals/d (n) 1.8 ± 1.1 Snacks/d (n)	

BMR, basal metabolic rate; CHO, carbohydrate; F, female; M, male; NR, not reported; NS, not statistically significant; TDEI, total daily energy intake; veg, vegetables.

[1] Values are mean or median (IQR) unless stated otherwise.
[2] Additional data provided by authors per request [33,36].
[3] Study included in the meta-analysis.
[4] Energy and/or macronutrient data during a work shift.
[5] Energy and/or macronutrient data reported as %TDEI.
[6] Energy and/or macronutrient data as percentage of BMR.
[7] Energy and/or macronutrient data for shifts calculated from percentage of 24-h dietary intake averaged across a work cycle.
[8] SD was calculated from standard error for the study by Reinberg et al. [67].
[*] Significant difference between 2 or more groups ($P < 0.05$).

Among rotating shift workers, the WMD in 24-hour energy between shift type (morning/day shift compared with night shift) was not statistically significant (WMD: 101 kJ; 95% CI: −651, 852 kJ; $P = 0.79$; $I^2 = 77\%$). Synthesized data in Table 4 show that all 10 studies explored dietary energy intake. Three reported no significant intraperson differences in energy intake between rotating shift types, whereas 7 found significant differences [18, 35,59,62,67,68,70]. Four studies indicated significantly lower energy intake on night shifts than that on day shifts [59], afternoon shifts [18,62], 12-hour shifts [62], or morning shifts [67].

Study or Subgroup	Rotational shift Mean [kJ]	Rotational shift SD [kJ]	Rotational shift Total	Regular day/morning Mean [kJ]	Regular day/morning SD [kJ]	Regular day/morning Total	Weight	Mean Difference IV, Random, 95% CI
1.1 Healthcare occupations								
Farias (53) 9h day vs 9-12h rotational[2]	8,548	2,675	33	10,444	4,673	17	0.6%	-1896.00 [-4297.55, 505.55]
Hulsegge (34) female 8.5h day vs 8.5h rotational[1,2]	7,457	1,700	198	7,200	1,210	58	6.3%	257.00 [-134.20, 648.20]
Hulsegge (34) male 8.5h day vs 8.5h rotational[1,2]	8,725	2,035	33	8,570	2,780	11	1.0%	155.00 [-1628.54, 1938.54]
Mansouri (56) day vs rotational	7,691	2,815	7	6,171	2,351	19	0.6%	1520.00 [-817.98, 3857.98]
Sathyanarayana (57) day vs rotational night	6,658	1,297	20	6,602	836	20	4.2%	56.00 [-620.27, 732.27]
1.2 Nurses & Aged Care								
Pepolonska (63) day vs12h rotational[2]	8,424	2,639	251	7,758	2,427	271	5.9%	666.00 [230.02, 1101.98]
Seychell (66) 12h day vs12h rotational[2]	8,646	2,742	68	7,210	2,035	29	2.6%	1436.00 [449.44, 2422.56]
Tada (50) day vs rotational	7,670	2,102	1579	7,704	2,022	1179	8.0%	-34.00 [-189.15, 121.15]
Varli (69) 8h day vs rotational[2]	7,352	2,759	56	7,092	1,805	54	3.1%	260.00 [-608.30, 1128.30]
Yoshizaki (51) 9h day vs 7-15h rotational[2]	7,662	2,068	1464	7,662	1,972	1095	8.0%	0.00 [-157.68, 157.68]
Yoshizaki (58) 9h day vs 9-15h rotational[2]	7,834	1,763	13	8,131	1,185	14	2.1%	-297.00 [-1438.82, 844.82]
1.3 Industrial & Factory workers								
Esquirol (60) 8h day vs 8h rotational[2]	9,797	2,005	100	9,362	1,720	98	5.2%	435.00 [-84.99, 954.99]
Lennernas (47) 8.5h day vs 8.5h 2-rotational[2,3]	12,000	3,200	34	11,100	3,000	19	1.1%	900.00 [-825.28, 2625.28]
Lennernas (47) 8.5h day vs 8.5h 3-rotational[2,3]	11,900	3,200	25	11,100	3,000	18	1.0%	800.00 [-1069.28, 2669.28]
Morikawa (49) 20-29y day vs no midnight shift[1]	9,337	3,278	80	8,658	2,546	84	3.0%	679.00 [-222.34, 1580.34]
Morikawa (49) 20-29y day vs midnight shift[1]	8,780	2,981	161	8,658	2,546	83	3.9%	122.00 [-593.57, 837.57]
Morikawa (49) 30-39y day vs no midnight shift[1]	9,136	2,625	53	8,914	2,554	118	3.2%	222.00 [-621.67, 1065.67]
Morikawa (49) 30-39y day vs midnight shift[1]	9,864	3,270	155	8,914	2,554	117	4.1%	950.00 [257.78, 1642.22]
Morikawa (49) 40-49y day vs no midnight shift[1]	9,182	2,252	92	9,140	2,784	192	4.6%	42.00 [-563.67, 647.67]
Morikawa (49) 40-49y day vs midnight shift[1]	9,692	3,479	175	9,140	2,784	192	4.3%	552.00 [-96.66, 1200.66]
Morikawa (49) 50-59y day vs no midnight shift[1]	9,131	3,014	101	8,830	2,529	260	4.2%	301.00 [-362.33, 964.33]
Morikawa (49) 50-59y day vs midnight shift[1]	9,529	3,035	132	8,830	2,529	259	4.6%	699.00 [96.57, 1301.43]
Romon (64) day vs rotational	10,316	21,644	71	10,748	22,405	70	0.1%	-432.00 [-7704.83, 6840.83]
Sudo (48) 8.7h day vs 8.7h early rotational[2,3]	7,121	1,784	47	8,185	1,641	22	3.2%	-1064.00 [-1918.60, -209.40]
Sudo (48) 8.7h day vs 8.5h late rotational[2,3]	6,448	2,633	46	8,185	1,641	22	2.5%	-1737.00 [-2761.28, -712.72]
1.4 Mixed occupations/unspecified								
Heath (46) 8.5h morning vs 8h rotational[2]	8,530	3,080	29	7,954	2,979	17	1.0%	576.00 [-1230.09, 2382.09]
Heath (46) 8.5h morning vs12h rotational[2]	9,318	2,852	29	7,954	2,979	16	1.0%	1364.00 [-427.12, 3155.12]
Manodpitipong (55) day vs rotational night	6,226	2,441	49	4,706	1,708	85	3.6%	1520.00 [746.07, 2293.93]
Wirth (38) day vs rotational	9,480	3,857	681	9,620	6,303	6412	6.8%	-140.00 [-468.20, 188.20]
Total (95% CI)			**5782**			**10851**	**100.0%**	**263.90 [69.93, 457.86]**

Heterogeneity: $Tau^2 = 116504.92$; $Chi^2 = 76.37$, df = 28 ($P < 0.00001$); $I^2 = 63\%$
Test for overall effect: $Z = 2.67$ ($P = 0.008$)

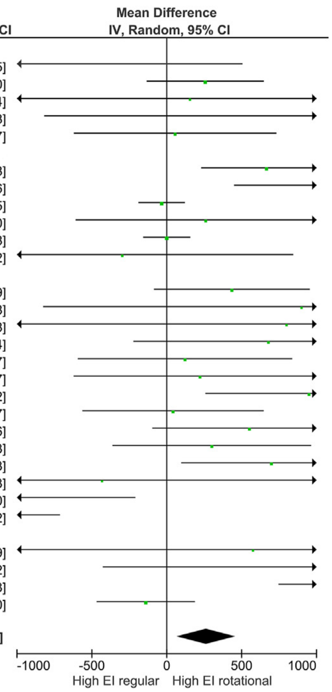

FIGURE 2. Meta-analysis to compare 24-hour energy intake between regular day/morning schedules and rotating shift work schedules. [1]Age and gender is only specified for multiple entries of the same study, where energy intake is stratified according to either age or gender. [2]Numerical values refer to the length of work hours where specified by studies, that is, 8-h day shift vs. 8-h rotating shift. [3]Two-rotational (morning and afternoon shifts) and 3-rotational (morning, afternoon, and night shifts) refer to the number of shift types within a work cycle, while "early" and "late" refer to shifts starting in the morning (06:00) and afternoon (13:40), respectively.

One study reported significantly higher energy intakes on night shift than on morning shift [70], whereas the other reported significantly lower energy intakes in evening shifts than in morning shifts [35]. In addition, a study that stratified results for female and male participant energy intakes found that only females showed significantly higher energy intake on night shift than that on the day shift [68].

All studies ($n = 10$) examined macronutrient intakes of which 7 reported on significant difference in protein [18,59,62,67,68], fat [18,35,59,70], or carbohydrate intake [18,68,70] according to shift types. Five studies indicated a significantly lower protein intake on rotating night shifts than on rotating afternoon shifts [18,62], morning shifts [67], or day shifts [59], including lower protein intake in females rather than males on night shift compared with those on day shift [68]. Two studies found a lower total fat intake on night shift than on either day [59] or afternoon shifts [18], and another reported a lower fat intake on evening shifts than on morning shifts [35]. By contrast, a fourth study reported a significantly higher fat intake on night than on morning shifts [70]. Significant differences in carbohydrate intake were found to be higher on night shifts than on morning shift [70] or day shifts for females only [68], whereas a third study found a higher carbohydrate intake on afternoon than on night shifts [18].

Dietary pattern comparisons: food type/quantity

Three studies explored dietary patterns, one of which reported on food type/quantity consumption and found significant differences in less meat intake on night compared with that on day shifts in both females and males and a higher intake of sweets on night than that on day shifts for females only [68].

Dietary pattern comparisons: food distribution/frequency

All 3 studies considered distribution/frequency of meals, snacks, or %TDEI across the day. Two studies reported on the number of meals consumed on shifts and found significant difference with fewer meals on evening and night shift than on morning shift [35] and fewer meals consumed on night shift than on day shift [68]. The latter study also reported significantly fewer snacks consumed on night than on day shift in females but not in males [68]. The third study reported that workers on non–night shifts recorded a significantly higher distribution of energy intake during the morning and evening, whereas rotating workers on night shift showed a higher energy intake redistributed to night time hours [61].

Quality assessment

Of the 31 included studies, 4 received a "positive" rating according to the Quality Criteria Checklist for Primary Research, whereas the remaining 27 studies were classified "neutral" (Table 5). The main limitations of the studies included bias in selection of study participants, limited comparability between groups/confounding factors, failing to specify whether researchers and participants were blinded to measurement of outcomes, not providing detail regarding work schedules and length of exposure to shift work, and lack of clarity on study funding/sponsorship and conflict of interest.

Discussion

This systematic review incorporated burgeoning research from studies investigating total energy intake and dietary

Study or Subgroup	Day/Morning shift Mean [kJ]	SD [kJ]	Total	Night shift Mean [kJ]	SD [kJ]	Total	Weight	Mean Difference IV, Random, 95% CI
Bonnell (33) 10h day vs 14h night²	11,709	2,298	19	11,077	3,377	19	8.9%	632.00 [-1204.68, 2468.68]
Bouillon-Minois (59) 10h day vs 14h night²	6,727	3,133	101	5,863	2,966	83	15.1%	864.00 [-19.45, 1747.45]
Fradkin (70) 8h morning vs 8h night²	6,027	2,183	132	6,819	2,221	132	17.4%	-792.00 [-1323.26, -260.74]
Lennernas (62) 8h morning vs 8h night²	15,300	3,600	16	14,900	3,900	16	5.8%	400.00 [-2200.65, 3000.65]
Mortas (36) 8h day vs 8h night²	9,453	1,616	10	8,689	2,269	10	9.5%	764.00 [-962.53, 2490.53]
Reinberg (67) 7h morning vs 9h night²	8,750	467	5	7,649	599	5	16.6%	1101.00 [435.25, 1766.75]
Ulusoy (68) female day vs 12h night¹ ²	8,796	1,496	32	9,667	1,591	32	16.0%	-871.00 [-1627.66, -114.34]
Ulusoy (68) male day vs 12h night¹ ²	10,383	1,443	12	11,191	2,226	12	10.8%	-808.00 [-2308.93, 692.93]
Total (95% CI)			**327**			**309**	**100.0%**	**100.52 [-650.79, 851.83]**

Heterogeneity: $Tau^2 = 771756.88$; $Chi^2 = 30.09$, df = 7 ($P < 0.0001$); $I^2 = 77\%$
Test for overall effect: $Z = 0.26$ ($P = 0.79$)

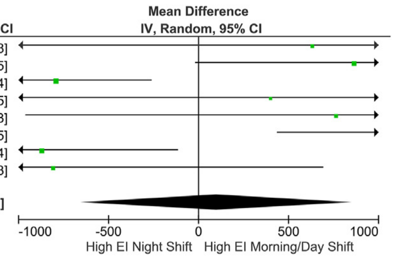

FIGURE 3. Meta-analysis of comparison of 24-hour energy intake between rotating day/morning shift and rotating night shift work schedules. [1]Age and gender is only specified for multiple entries of the same study, where energy intake is stratified according to either age or gender. [2]Numerical values refer to the length of work hours where specified by studies, that is, 8-h day shift vs. 8-h rotating shift.

patterns associated with regular day work, shift work, and rotating shift work schedules. The effects of rotating shift work schedules on these dietary parameters may partly explain the comparatively worsened disease risk experienced in rotating shift work populations.

Our first meta-analysis of 18 studies suggests rotating shift schedules contribute to a higher energy intake in workers than regular daytime schedules. This result contrasts with previous findings reporting energy intake to be similar between day work and shift work cohorts [24,27,28]; however, the addition of 11 studies since the meta-analysis investigating energy intake between day and rotating night shift workers by Bonham et al. [27] and the use of 13 additional studies since Cayanan et al. [28] may account for our updated findings. Both reviews conducted meta-analyses with rotating shift schedules during night shift and compared with regular day schedules, whereas this review compared varied rotating shifts (early rotating, late rotating, 2-shift rotating, 3-shift rotating, and night shift rotating schedules) with regular morning/day schedules, and the higher energy outcome in rotating shift work schedules may reflect these comparisons. The summary effect of our meta-analysis showed that 21 of the 29 comparisons (including multiple subgroup comparisons between day work and rotating shifts within the 18 studies) indicated a higher energy intake in the rotational groups irrespective of significance levels found in individual studies.

There was a large variability in energy intake both within and across studies in our first meta-analysis, as evidenced by a moderate to high heterogeneity ($I^2 = 63\%$). Although our results show rotating shift workers typically have higher mean energy intakes than day workers, in some study populations, the mean difference was as small as 42 kJ [49], whereas the greatest difference was 1520 kJ [55,56]. Average 24-hour energy intakes ranged from 4706 to 12,000 kJ. The variation in energy intake could be due to length of shifts and/or differences in the demands of the occupation, which also varied across the studies included. However, details regarding the nature of the roles was not consistently apparent, making conclusions on differences in the nature of shift work difficult to quantify. Variation is also inherent in reporting of dietary intakes, and different dietary intake methods individually have limitations [71] and are susceptible to underreporting where self-reported methods are used [72]. Because all studies were either observational or cross-sectional, unblinded participants were likely cognisant of dietary intake being monitored, which potentially influenced changes in usual eating behavior. Different dietary intake measures were adopted by the included studies, which individually used diet history questionnaires [60], 24-hour dietary recalls [38,47,53,55,57,69], FFQs [46,49–51,63,66], food diaries [34], remote food photography/photographic dietary assessment [48,56], food records [48,53,58,64], or a combination of these methods [48,53]. The duration for dietary data collection ranged from 1 d [38,55,57,58] to 4 d [48,56] between studies, making comparability between work schedule types less consistent. Furthermore, dietary data collected by methods other than FFQ for rotating workers occurred on a combination of shifts and days off [34,47,60], during shifts [48,56,69], during day shift [58], or did not specify whether collected on shift or days off [38,53,55,57,64]. Although there is a great heterogeneity between regular day and rotating shift schedules, rotating shift patterns themselves showed a great variability with 7- to 15-hour rotating shift lengths, whereas day schedules were 8–12 h long. All these factors associated with dietary data collection contribute to variability when reporting energy intake and may limit the generalizability of these findings.

The consideration of physical activity/energy expenditure was also inconsistent across studies for interpreting energy intakes. Ten of the 18 studies in our analysis compared levels of physical activity between groups or accounted for physical activity [34,47,48,50,53,56,58,60,66,69]. Seven of these studies reported no difference in energy intake between day workers and rotating shift workers [34,47,50,53,58,60,69], whereas 1 study found lower energy intake in rotating shift workers [48]. The remaining 2 studies did not directly compare energy intake between rotating shift workers and day workers [56,66]. Occupational groups are known to vary in work-related physical activity, and the roles represented in a proportion of these studies require a higher than usual energy expenditure, such as for industrial work, whereas other roles such as health care administrative roles are typically more sedentary. Regardless, obesity is related to increases in food energy more so than lack of exercise, and a 100-kJ/day increase in energy intake may result in 0.5 kg weight gain over a year and an estimated 1 kg over 3 y [73]. Thus, an average 264-kJ higher 24-hour energy intake, as indicated by our meta-analysis, can contribute to gradual weight gain and a higher metabolic risk in rotating shift work populations, especially if consumed later during the 24-hour day at a time when nutrient metabolism is suboptimal.

Macronutrient distribution and dietary patterns were explored to further understand the higher mean energy intake observed in rotating shift workers in this review. Sixteen studies reported on macronutrient composition, of which 7 observed significant differences in protein, total fat, or carbohydrate intakes through a work schedule type. Although there were obvious discrepancies between studies, there may be a trend in

TABLE 5
Quality Assessment of the included studies using the Quality Criteria Checklist for Primary Research (Academy of Nutrition and Dietetics)

Study [reference]	Study design	Quality rating	Validity items[1]									
			1	2	3	4	5	6	7	8	9	10
Bonnell et al. [33]	Cross-sectional	Neutral	✓	×	✓	✓	×	✓	✓	✓	✓	✓
Bouillon-Minois et al. [59]	Observational	Neutral	✓	✓	UC	✓	NA	✓	✓	✓	✓	✓
Chen et al. [37]	Observational	Neutral	✓	UC	×	✓	NA	UC	UC	UC	✓	✓
Esquirol et al. [60]	Cross-sectional	Positive	✓	✓	✓	UC	×	✓	✓	✓	UC	UC
Farias et al. [53]	Cross-sectional	Neutral	✓	UC	✓	✓	×	✓	✓	✓	✓	✓
Flanagan et al. [61]	Cross-sectional	Neutral	✓	UC	✓	UC	UC	UC	✓	✓	✓	✓
Fradkin et al. [70]	Cross-sectional	Neutral	✓	×	✓	×	×	NA	✓	×	✓	×
Han et al. [54]	Cross-sectional	Neutral	✓	UC	UC	✓	UC	UC	✓	✓	✓	✓
Heath et al. [46]	Cross-sectional	Neutral	✓	✓	×	✓	×	✓	✓	✓	✓	✓
Hulsegge et al. [34]	Cross-sectional	Neutral	✓	✓	UC	NA	×	UC	✓	✓	✓	✓
Kosmadopoulos et al. [35]	Observational	Neutral	✓	✓	✓	NA	×	✓	UC	✓	✓	✓
Lennernas et al. [47]	Cross-sectional	Neutral	✓	UC	×	✓	✓	✓	✓	✓	✓	UC
Lennernas et al. [62]	Cross-sectional	Neutral	✓	UC	✓	✓	UC	✓	✓	✓	✓	UC
Lennernas et al. [18]	Cross-sectional	Neutral	✓	UC	✓	NA	NA	✓	✓	✓	✓	UC
Manodpitipong et al. [55]	Cross-sectional	Neutral	✓	✓	×	UC	UC	UC	✓	✓	✓	✓
Mansouri et al. [56]	Observational	Neutral	✓	✓	✓	✓	NA	UC	✓	✓	✓	✓
Morikawa et al. [49]	Cross-sectional	Neutral	✓	✓	✓	NA	✓	UC	✓	✓	✓	UC
Mortaş et al. [36]	Observational	Neutral	✓	×	✓	UC	NA	✓	✓	✓	✓	✓
Peplonska et al. [63]	Cross-sectional	Neutral	✓	✓	×	✓	UC	UC	✓	✓	✓	UC
Reinberg et al. [67]	Observational	Neutral	✓	×	UC	NA	UC	✓	✓	✓	UC	UC
Romon et al. [64]	Cross-sectional	Positive	✓	✓	✓	✓	NA	✓	✓	✓	UC	UC
Sathyanarayana and Gangadharaiah [57]	Cross-sectional	Neutral	✓	×	×	UC	NA	✓	×	UC	×	✓
Seibt et al. [65]	Cross-sectional	Neutral	✓	✓	×	×	×	UC	✓	✓	✓	✓
Seychell and Reeves [66]	Cross-sectional	Positive	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
Sudo and Ohtsuka [48]	Cross-sectional	Positive	✓	✓	✓	✓	NA	✓	✓	✓	✓	UC
Tada et al. [50]	Cross-sectional	Neutral	✓	✓	✓	UC	×	×	✓	✓	✓	✓
Ulusoy et al. [68]	Cross-sectional	Neutral	✓	UC	✓	✓	NA	UC	✓	✓	✓	✓
Varli and Bilici [69]	Cross-sectional	Neutral	✓	UC	UC	NA	×	UC	✓	✓	UC	UC
Wirth et al. [38]	Cross-sectional	Neutral	✓	✓	×	NA	NA	×	UC	✓	✓	✓
Yoshizaki et al. [58]	Cross-sectional	Neutral	✓	×	✓	NA	UC	NA	UC	UC	✓	✓
Yoshizaki et al. [51]	Cross-sectional	Neutral	✓	×	×	NA	×	✓	✓	✓	✓	✓

NA, not applicable; UC, unclear; ×, criteria has not been satisfied: ✓, criteria has been satisfied.
[1] Validity items: *1*) clarity of research question; *2*) nil selection bias of study participants; *3*) comparability of study groups; *4*) description of withdrawals; *5*) utilization of blinding; *6*) detailed description of intervention/exposure factor; *7*) validity/reliability of outcome measures; *8*) appropriate statistical methods; *9*) consideration of limitations/bias in the reported result; and *10*) declaration of funding, sponsorship, and nil conflict of interest. Highlighted columns indicate the validity items required for a positive quality rating.

rotating shift workers toward the consumption of less protein [48,50,51] and carbohydrate [48,53] and more total fat [63,66] by comparison with day workers, and this may also be reflected in a higher total energy intake. Compared with that of day workers, dietary patterns of rotating shift workers seem to consume more meals per day, involve more snacking at night and have a lower likelihood of consistently having 3 meals per day [54,60]. Rotating shift workers may also redistribute a greater percentage of daily energy to the second half of the day owing to their work schedules [60]. A consequence of energy redistribution toward the latter half of the day is perturbed nutrient metabolism [74]. A review and meta-analyses of acute postprandial studies measuring glucose and insulin responses in the day and at night using matched meals suggest worsened glucose tolerance at night compared with that at the day [75], contributing to an increase in risk factors for metabolic disease [14,17,18]. Regarding food type and quantity, 3 studies indicated rotating shift workers consume fewer core foods (dairy, meat, fruit, and vegetables) and more discretionary foods/drinks (sweetened beverages, fried foods, fatty foods, confectionery, and alcoholic drinks) than day workers [49–51]. It may be that the combination of night time eating, increased daily mean energy intake, a higher fat intake, and less regular/less healthy dietary patterns are contributing to a higher risk of chronic disease in rotating shift workers.

Intraperson energy intakes within rotating shift types as shown in the second meta-analysis did not differ for between individuals in rotating morning/day shifts and those in rotating night shifts. However, there was a large variation in the summary effect of the studies, with differences of 400 to 1101 kJ in individual energy intakes according to rotating shift type. Heterogeneity ($I^2 = 77\%$) was high, which may be an indication of the variation within rotating shift patterns and a number of dietary assessment methods/periods used between the studies. Shift lengths ranged from 8 to 14 h, and dietary assessment tools included were 24-hour recalls [33,59,62,68], food diaries [70], and dietary records [36,67], wherein the dietary data collection period varied from 2 d to 8 consecutive weeks.

It was not possible to identify a shift pattern associated with the higher energy intake in rotating shift workers. Furthermore the inconsistent findings in macronutrient composition observed from a smaller number of studies meant it was not possible to attribute the higher energy intake to a particular dietary composition. Moreover, it was not possible to identify macronutrient differences within shifts. Although all 10 included studies examined macronutrient composition, a trend toward a lower protein [18,59,62,67,68] and lower fat intake [18,59] was only observed in some studies comparing night shifts with rotating day or morning shift types. Furthermore, dietary patterns of rotating shift workers according to shift type were explored only in 3 studies. Rotating night shifts differed in workers consuming fewer meals/snacks compared with those in rotating morning [35] or rotating day shifts; however, the latter comparison was observed in females only [68]. Workers on night shifts also consumed less meat by both genders and more discretionary foods (females only) [68], and a greater proportion of daily energy intake was redistributed to night time hours [61]. Some of these descriptions of rotating night shift dietary patterns mirror the general comparisons made between rotating shift workers and regular daytime workers, namely the consumption of fewer core foods, more discretionary foods, and consuming a larger percentage of daily energy at night.

Strengths and limitations

This review explored the effect of rotating shift schedules on the average energy intakes and dietary patterns of rotating shift workers by synthesizing data from a large number of study participants (n = 10,612). Limitations of the included studies were the inconsistency in inclusion of dietary pattern data or, when included, the data were typically limited to either type/amount of foods consumed or frequency/distribution of foods. Hence, future studies are recommended to consider a more robust interpretation of dietary pattern data representative of the studied shift working population. Of the 29 studies, 4 were quality rated as positive based on quality, whereas the remaining studies were rated neutral owing to a number of factors such as inconsistent dietary assessment methods, and in some cases, studies used a single 24-hour dietary recall/dietary record or a FFQ, which cannot determine usual dietary intake on and off shift. Moreover, studies lacked clarity around when dietary data were collected in relation to shift schedules and/or included nonwork days within the dietary collection period, influencing the consistency of dietary intake outcomes. The authors are of the opinion that some of these limitations can be addressed by ensuring repeated 24-hour dietary recalls/or day food diaries, which cover all shift types, and by specifying intake related to shift schedule timing. Furthermore, objective measures of dietary intake/quality could be achieved in future studies by inclusion of nutritional biomarkers that indicate fruit and vegetable intakes (vitamin C and carotenoids) [76] or biomarkers in blood cells to indicate intake of fatty acids (such as ω-3 index) [77]. In addition, a number of studies were not clear on confounding factors such as physical activity/energy expenditure, which is known to affect dietary energy intakes of workers. It is recommended that future studies use objective energy expenditure measures such as easily worn activity monitors used in conjunction with dietary assessment, work schedules, and sleep records of shift workers to differentiate energy expenditure across 24 h and across shift types. Although we have been able to examine energy and macronutrient intake at night to try and differentiate between shifts, there are other factors that may contribute to food choices such as timing and availability of meal breaks [78], social eating with colleagues and family [79], and eating owing to stress or trying to remain alert [25,80]. This review was influenced by limitations such as high heterogeneity and the use of only English-language publications. A publication bias assessment was also not conducted because of studies being cross-sectional or observational rather than intervention based. However, a statistical significance for a higher energy intake in rotating shift workers was attained because of a comparatively larger number of studies and overall sample size. The varied representation of different shift working industries and occupations, genders, and ages of participants can also be seen as a strength. Overall, the focus of this review on rotating shift workers as a unique shift working group and the rigorous study selection process and thorough methodology, which incorporated energy intake, macronutrient composition, and dietary patterns, are strengths supporting the findings of this systematic review.

Conclusion

Our findings show that rotating shift workers as a separate shift working group record a higher average 24-hour energy intake. Rotating shift workers seem to exhibit aspects of compromised dietary patterns when compared with day workers, including having irregular and more frequent meals, more snacking or eating at night, a lower consumption of core foods, and a higher intake of discretionary foods. The increased risk of cardiometabolic conditions apparent in rotating shift workers suggests that modifiable risk factors, such as the improvement of these dietary behaviors, are critical to help mitigate against the detrimental impact of rotating shift work schedules. Acknowledging circadian disruption as an unmodifiable contributing factor of higher disease risk observed in shift workers, clearly understanding aspects of the dietary behaviors of rotating shift workers will in turn enable informed and practical dietary advice to improve the health outcomes of this unique shift working population.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.advnut.2023.01.006.

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