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Eating and shift work – effects on habits, metabolism, and performance

by Arne Lowden, PhD,[1] Claudia Moreno, PhD,[2] Ulf Holmbäck, PhD,[3] Maria Lennernäs, PhD[4], Philip Tucker, PhD[5]

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Compared to individuals who work during the day, shift workers are at higher risk of a range of metabolic disorders and diseases (eg, obesity, cardiovascular disease, peptic ulcers, gastrointestinal problems, failure to control blood sugar levels, and metabolic syndrome). At least some of these complaints may be linked to the quality of the diet and irregular timing of eating, however other factors that affect metabolism are likely to play a part, including psychosocial stress, disrupted circadian rhythms, sleep debt, physical inactivity, and insufficient time for rest and revitalization. In this overview, we examine studies on food and nutrition among shift workers [ie, dietary assessment (designs, methods, variables) and the factors that might influence eating habits and metabolic parameters]. The discussion focuses on the quality of existing dietary assessment data, nutritional status parameters (particularly in obesity), the effect of circadian disruptions, and the possible implications for performance at work. We conclude with some dietary guidelines as a basis for managing the nutrition of shift workers.

Key terms diet; food; meal pattern; nocturnal eating; night work; night eating; nutrition.

Eating behavior might be altered by working shifts, especially when night work is involved (1, 2), due to a diverse range of biological, social, and cultural factors (3). For example, it has been suggested that night work causes a conflict between socially determined meal schedules and the circadian biological rhythms in hunger, satiety, and metabolism. Nocturnal eating causes disturbances of intestinal motility, affecting the digestion, absorption, and utilization of pharmacological drugs and nutrients (4, 5). From a chronobiological point of view, the human species is diurnal (ie, active during the day), which explains why night workers tend to have a decreased appetite during the night when the organism is programmed for restitution, fasting, and endogenous mobilization of blood glucose (6, 7). From a psychosocial perspective, shift workers commonly experience a mismatch between their daily routines (including meal times) and those of family and friends, which may further serve to disrupt their eating habits. The extent to which eating behavior is impacted by shift working is also likely to depend on local cultural norms (eg, the number and timing of daily eating events and what is typically eaten at certain times) (8).

However, it is difficult to make dietary recommendations for shift workers. Firstly, we do not know whether shift workers should eat during the night or not. Secondly, even if nocturnal eating is to be encouraged, we lack definitive evidence regarding what should be eaten or avoided. Thirdly, nutritious and palatable foods might not be available when working night shifts. Finally, eating at night might improve wellbeing but simultaneously impair metabolism.

The biological, non-cultural regulation of food intake in human beings is primarily influenced by the need to consume enough energy to avoid weight loss and, in the second place, factors relating to the time of day. Regulation of eating is centered in the hypothalamus and linked to circadian rhythms in both eating and sleep. Human beings are diurnal such that nocturnal sleep is associated with a shift from the catabolic to anabolic process (ie, from energy expenditure to growth and repair). This implies that there is an orientation towards mainly catabolic processes and a high metabolic rate in the body during daytime work. From an energy perspective, the body is ingesting, using, and also storing energy during the

1 Stress Research Institute, University of Stockholm, Stockholm, Sweden.
2 School of Public Health, University of São Paulo, São Paulo, Brazil.
3 Department of Public Health and Caring Sciences, Clinical Nutrition and Metabolism, Uppsala University, Uppsala, Sweden.
4 Kristianstad University College, Kristianstad, and Uppsala University, Uppsala, Sweden.
5 Department of Psychology, Swansea University, Swansea, Wales, United Kingdom.

Correspondence to: Dr A Lowden, Stockholm University, Stress Research Institute, 109 91 Stockholm, Sweden. [E-mail: arne.lowden@stress.su.se]

daytime. At night, catabolic activity must be present due to the need for mobilization of endogenous energy during fasting and sleep, but anabolic restorative processes are also present. Thus, anabolic and catabolic processes occur in parallel during both day and night. During the night, growth hormone (released during the first deep-sleep phase) and cortisol induce internal energy mobilization of blood glucose (ie, the release of blood glucose from glycogen stored in the liver and also gluconeogenesis from amino acids). Available blood glucose levels are reduced at night and glucose is "spared" so as to provide energy for the central nervous system, resulting in a resistance to nocturnal energy in muscle tissues. This has been suggested as the reason for impaired glucose tolerance among shift workers (9, 10). Hunger and satiety hormones are linked to circadian rhythms in metabolism so as to facilitate nocturnal fasting and sleep. This may account for the depressed appetite that is often observed during night work.

As well as the potentially negative physiological effects of eating at night, shift workers' eating behavior may also impact their neural functioning. Short-term changes in food intake are known to affect many aspects of cognitive performance, mood, and wakefulness (11). For example, the cognitive-behavioral consequences of both short- and long-term restrictions of food intake (eg, skipping meals or incomplete food composition and fasting, dieting, and malnutrition, respectively) have been observed. Short-term effects are related to (a lack of) energy supply, while long-term effects concern (a lack of) the supply of essential nutrients (ie, vitamins, minerals, and essential amino and fatty acids that are necessary for the functioning of the senses and biochemical processes).

This discussion paper aims to examine the impact of shift work hours on, and the role of eating behavior in, the health and performance of shift workers. In doing so, we shall begin by seeking to identify what is known about shift workers' eating behavior and the factors that shape it. We shall then consider how their dietary habits impact metabolism and performance, looking at both health outcomes and the possible underlying mechanisms. On the basis of these considerations, we shall conclude by identifying a set of dietary guidelines that may help to minimize the health problems experienced by shift workers.

Definitions

For the purposes of the current discussion, the term "eating behavior" will be used to encompass the following dimensions of the dietary assessment: (i) the timing and frequency of eating; (ii) meal composition; (iii) food composition; and (iv) the habitual average intake of energy and essential non-energy yielding nutrients (eg, vitamins, minerals, fatty and amino acids, and bioactive components that cannot by synthesized within the body).

Due to the complexity of categorizing eating events in an objective and reliable way, many researchers would probably define "meal patterns" as the daily frequency of eating events, roughly categorized into "meals" and/or "snacks". However, such a classification does not provide any information about the nutritional content or quality of the eating events (12). From a biological perspective, a meal consists of biochemical compounds, whereas, from a sociological perspective, a meal is considered a ritual and recognized by the individual as something more than "fuel" (13).

Nutritional surveys of shift workers – an overview

Table 1 summarizes studies involving the dietary assessment of shift workers that have been undertaken since the late 1960s, when interest in nutrition research in shift work began. All included studies are field studies and report dietary data collected over the full 24-hour period (ie, before, during, and after work). Relatively few studies involved comparisons within subjects, with nearly half of the studies instead reporting statistical comparisons between groups (eg, comparing a group of evening workers with night workers). However, the majority of studies included comparisons between shift and day workers (the case–control approach). The amount of nutrient information reported varied considerably between studies. Most studies provided information on meal times and the majority also included measures of total energy, macronutrients, and meal frequency. The methods for classification of eating events varied between studies while the nomenclature used was, with one exception, unreliable (ie, terms like "breakfast" or "main meal" do not reflect the nutritional quality of what was ingested or the time of day it was ingested). However, only a few of the studies presented analyses of food items, macronutrient composition (energy percentage), vitamins, minerals, or nutrient- or energy-density. Less than half of the studies collected dietary data across a complete shift cycle (eg, a sequence of consecutive night shifts and free days for the same subjects). Relatively few studies provided nutritional recommendations on the basis of their findings, while fewer still provided evaluations of their participants' nutritional status. Taken as a whole, the results of the studies clearly demonstrate that shift work does not dramatically alter the individual's total energy intake, but that the worker's temporal distribution of eating is affected.

The study by Debry et al (14) was one of the first to demonstrate that the total energy intake for workers on alternating shifts is similar to that of day workers. However, the diets of the shift workers were found to be richer in animal fat and proteins [a finding that was subsequently

Table 1. Dietary assessment field studies in shift workers, evaluation criteria, design and main results. [INS = individual nutrition status, M = morning; A = afternoon; N = night, D = day; CC=case–control; Eco=ecological; → = similar across 24 hours, ↑ = higher , ↓ = lower].

Reference	Dietary assessment method	Shifts studied	# days studied	Mean age (years)	Gender (% male)	Study design	Shift workers (#)	Day workers (#)	Nutritional information	Diet across shift cycle	Evaluation versus recommendations	Evaluation versus INS [a]	Nutritional results, shift workers compared to controls or between shifts
Debry et al, 1967 (14)	Diary	M/A/N	4 days	43	100	Eco	100	100	Food items, total energy, macronutrients, meal frequency, frequency of categorized eating types, meal times	No	No	No	→ Total energy intake M/A/N
Reinberg et al, 1979 (16)	Diary	M/A/N	8 weeks	26	100	Time trend	5	2	Total energy, macronutrients, meal frequency, meal times	Yes	No	No	→ Total energy intake M/A/N; ↑ nibbling N
Cervinka et al, 1984 (20)	Diary	M/A/N	7 days	36	100	CC	28	14	Total energy, meal frequency, meal times	Yes	No	No	↑ Caloric intake N
Attia et al, 1985 (6)	Diary, 24-h recall	M/A/N 24/48h	15–21 days	19–45	100	Eco	39	10	Meal frequency & times	Yes	No	No	↓ Appetite N
Romon-Rousseaux et al, 1987 (27)	Diary	M/A/N	4 days	39	100	CC	74	20	Total energy, macronutrients, meal frequency, meal times	No	No	No	→ Total energy intake M/A/N
Duchon & Keran, 1990 (82)	Questionnaire	M/A/N	4 days	36	99	Eco	101		Meal frequency & times	No	No	No	Low health related to changed meal frequency at N
Knutsson et al, 1990 (22)	Diary	M/A/N	4 days	21	100	Prospective	12	13	Food items, total energy, macronutrients, vitamins, minerals	No	No	Yes	↓ Dietary fibers N (vegetables, potatoes)
Kräuchi et al, 1990 (79)	Diary	M/A/N	13 days	29	0	Time trend	28		Meal frequency & times	Yes	No	No	→ Meal content M/A/N; ↑ sweets/alert N
Nikolova et al, 1990 (15)	Questionnaire	12D, 12N	3 days	≈40	100	CC	98	17	Total energy, macronutrients	No	No	No	↑ High animal fat N
Linseisen & Wolfram, 1994 (23)	Weight records	N	7 days	34	100	CC	24	25	Total energy, macronutrients, vitamins, minerals, meal times	Yes	Yes	Yes	↓ Vitamins A,D, zinc, fibers, than recommended
Lennernäs et al, 1994 (19)	Diary, 24-h recall	M/A/N	5 days	36	100	Time trend	22		Total energy, macronutrients, meal frequency, meal times	Yes	No	Yes	→ Total energy intake M/A/N; ↓ energy during N
Lennernäs et al, 1994 (28)	Interview, 24-h recall	M/A/N 12D	5 days	35	100	Time trend	16		Total energy, macronutrients, vitamins, minerals, nutrient density, energy density	No	Yes		→ Total energy intake M/A/N; ↑ energy intake 12 D
Lennernäs, et al, 1995 (29)	Interview, 24-h recall	M/A/N	≈1 week	25–55	100	Time trend	59	37	Total energy, macronutrients, vitamins, minerals, nutrient density, energy density, meal times	Yes	Yes	No	→ Total energy intake M/A/N; ↓ energy during N
Geliebter et al, 2000 (59)	Questionnaire, retrospect	A/N	1 day	42	51	CC	49	36	Meal frequency & times	No	No	No	↑ Weight gain N; ↓ meal frequency N
Landström et al, 2001 (92)	Wake diary	10D, 10N	2 days	–	100	Experimental	6	6	Food items, total energy, macronutrients, nutrient density, energy density, meal frequency, frequency of categorized eating types, meal times	No	Yes	No	→ Wakefulness high/low fat
Sudo & Ohtsuka, 2001 (37)	Diary photo assessment	M/A	4 days	26	0	CC	93	44	Food items, total energy, macronutrients, minerals, nutrient density, meal frequency, frequency of categorized eating types, meal times	No	Yes	Yes	↓ Energy, meal frequency / quality A

(continued)

Table 1. Continued.

Reference	Dietary assessment method	Shifts studied	# days studied	Mean age (years)	Gender (% male)	Study design	Shift workers (N)	Day workers (N)	Nutritional information	Diet across shift cycle	Evaluation versus recommendations	Evaluation versus INS [a]	Nutritional results, shift workers compared to controls or between shifts
de Assis et al, 2003 (18)	Diary, 24-h recall	M/A/N	3 days	30	100	CC	66		Food items, total energy, macronutrients, meal frequency, frequency of categorized eating types, meal times	No	Yes	No	→ Total energy intake M/A/N; nergy intake M/A/N
Waterhouse et al, 2003 (25)	Questionnaire every 3 hours	10N	7 days	26 & 43	12	CC	43	50	Meal frequency & times	Yes	No	No	↓ Meal frequency during N; ↓ appetite during N
Pasqua & Moreno, 2004 (17)	Diary	M/A/N	3 days	33	100	Time trend	28		Total energy, macronutrients, meal frequency, meal times	No	Yes	No	↑ Caloric intake winter versus summer
Morikawa et al, 2008 (21)	Questionnaire 1-month recall	M/N	1 month	20–59	100	CC	949	1305	Total energy, macronutrients, vitamins, frequency of categorized eating types	Yes	No	No	→ Total energy intake M/N in young but ↑ in old
Esquirol et al, 2009 (30)	Diary	M/A/N	4 days	50	100	CC	100	98	Total energy, meal frequency	No	No	No	→ Total energy intake M/A/N; ↑ meal frequency N

[a] Non-BMI (body mass index) based methodology.

replicated in a study of 12-hour shift workers (15)]. Subsequently, Reinberg et al (16) reported an eight-week diary study of seven refinery workers (including five shift workers), in which they also observed no change in total energy intake associated with working shifts, despite an increase in the frequency of meals taken. However, in this case there was an increase in carbohydrate intake that was linked to increased snacking at night. Similarly, Pasqua & Moreno (17) found that, while workers on morning, afternoon, or night shifts (7, 10, and 11 subjects, respectively) did not differ in terms of total energy intake, they differed with respect to the distribution of intakes over 24 hours. Likewise, a study of 66 garbage collection workers (18) found that total 24-hour energy intake did not differ between groups working the three different shifts. However, the night workers consumed more energy at work (due to a larger proportion of fat and carbohydrate) when compared to the other workers. Lennernäs et al (19) followed the eating habits of 22 industrial shift workers in a within-subject design as they alternated between morning, afternoon, and night shifts. Consistent with the previously cited studies, they found that total dietary intake (including energy) did not differ between 24-hour periods (ie, overall energy intake was unaffected with respect to which shift was being worked). However, in contrast to some of the above studies, dietary intake was found to be lower during the night shift. During morning, afternoon, and night shifts, respectively, 47±17%; 51±16%, and 35±10% of 24-hour energy intakes were consumed.

In contrast to the majority of these findings that suggest the overall energy intake is unaffected by shift work, Cervinka et al (20) reported higher energy intake among night workers compared with controls. This was thought to be linked to higher levels of obesity among the night workers. More recently, a Japanese study (21) of 2254 male manual workers employed at a manufacturing company also found, in contrast to earlier studies, that total energy intake was higher among night than day workers. However, this was only the case among older, more experienced night shift workers (>30 years). There was no such difference between night and day shifts among younger workers, with the younger night shift workers tending to eat less than their older night-working colleagues.

Besides energy intake, research has also identified the impact of shift work on other aspects of dietary intake. Knutson et al (22) found that the consumption of dietary fibers was reduced six months after starting shift work. This was mainly due to a reduction in the consumption of green vegetables/potatoes and an increase in sucrose resulting from a higher intake of soft drinks. Linseisen et al (23) found that the consumption of dietary fibers, zinc, and vitamins A and D was reduced to below the daily recommended levels in a group of permanent night workers. This might be an effect of altered meal pattern or food choice where, for example, the preparation of hot meals including a variety of foods is reduced and replaced by ingestion of single food items or bread-based meals.

Shift workers, and particularly night workers, tend to have more irregular eating patterns than their day counterparts. In an early study of 1300 industrial shift workers, Tagaki (24) reported that, while the habit of consuming three daily meals was maintained, morning and night shift workers had less regular meal patterns. Several studies have also reported that workers on the night shift tend to eat more frequently, with multiple snacks commonly being taken during the night shift instead of a full meal (16, 18, 25). Nyberg (26) concluded that shift workers' eating habits could be described as consuming "plenty of foods but few meals". This may be one factor contributing to the higher energy intake observed at night in some studies. Another possible factor could be the tendency for night workers to consume easy-to-prepare food that is characterized by high-energy content.

In summary, the majority of evidence indicates that total energy intake over 24 hours does not vary between day and shift workers or, to any large extent, between different work shifts (14, 16, 18, 19, 27–30); although this may be dependent on individual differences (eg, age). However, shift working (and when the shift work period occurs) does appear to affect the amount eaten, the quality of the dietary intake, and energy distribution over the course of the day. Several studies report a greater tendency to eat small amounts frequently ("nibbling behavior") during the night shift. Also, eating tends to be more irregular during the night shift period. Several other factors may also contribute to inconsistencies between studies, such as cultural differences, differences in the quality of available food (eg, at night) and changes in attitudes over time (eg, due to the spread of nutritional advice and awareness).

Organizational and social aspects

In order to fully understand the eating habits of shift workers, it is necessary to consider the organizational and social context in which eating takes place. The timing and content of meals are constrained by task demands in the workplace and social, domestic, and rest requirements outside of work. Moreover, eating is a social activity and so a shift worker's eating habits will be influenced by those of their family, friends, and work colleagues. It is also important to consider the role that the social context of eating plays in health promotion and obesity prevention. For example, eating in a relaxed ambience promotes the activation of anti-stress systems (31). Thus it is important to study whether shift work affects the experience of eating and the possibility to eat in a pleasant ambiance.

Taking time for meals is seldom prioritized in the workplace (26) and this may be especially true of night work if, for example, staffing levels are lower at night. In a study of night working nurses, Waterhouse et al (25) found that eating on the nightshift was driven more by scheduling constraints (eg, eating when it is convenient) than by hunger. They also reported that the nurses tended to opt for cold food snacks at night, even though hot food was available. This has also been reported in male populations (29). This suggests that, in at least some cases, the snacking that is commonly observed on the night shift (see above) is not simply a function of limited facilities. In another study (32), it was shown that during periods of structured activity (ie, work) there was little relation between level of hunger and the amount or type of food consumed, while stronger associations were observed during unstructured time. The same study also found that there was a stronger association between hunger and what was eaten when the meal had a social component. The findings of these studies suggest that factors such as time availability and social context play an important role in determining food intake during work hours, particularly at night.

Eating in the workplace is thus influenced by the quality of food and dining facilities that are provided and also the attitude towards food and eating at work (26, 33). It may be that some workplaces provide only limited menu choices on certain shifts, with the result that energy intake is reduced during that time. Fischer & Atkinson (34) described one such example where 22% of military air crews reporting diet-related symptoms were exposed to work-related inadequate eating. It may be argued that if shift workers are to be encouraged to maintain particular eating habits in the workplace, they need to be provided with both the opportunity and the appropriate facilities. For example, this may mean allowing for the meal to be eaten away from the workplace, with colleagues, in as pleasant surroundings as possible [see also (25)].

It is also important to consider meals taken outside the workplace. Night workers commonly experience a mismatch between their own routine and those of their families and friends. For some shift workers, meal times are a relatively rare opportunity to spend "quality time" with their family. Thus a night worker might choose to dine with their family in the evening before going to work in preference to taking a large meal during or after the nightshift. Alternatively, they may choose to take another large meal during the nightshift, which could result in overeating. If the night worker chooses not to eat with the family, then it is likely that the meals at home will be self-prepared and eaten alone. As noted above, this may result in the consumption of poorer quality, less healthy meals.

Schedule design may also contribute to the problems that shift workers experience in this regard. Sleep and food intake are basic needs that cannot be fulfilled concurrently and therefore may, on occasion, compete with each other. For example, eating habits may be negatively affected by schedules that feature short breaks between shifts (35). Axelsson et al (36) have illustrated an example of such a situation. Figure 1 shows actigraph (motion logger) output reflecting the sleep–wake pattern of a shift worker on a rapidly rotating 8-hour schedule at a papermill. The female in question worked a sequence of single night, afternoon, and morning shifts, each separated by breaks of only 8 hours. During these 8-hour inter-shift breaks, she had to find time for sleep, food preparation, meal intake, travel to work, personal hygiene and, if possible, family interactions. As a result, not only was there insufficient time available for the preparation of high quality meals, but also sleep was compromised. The workers in this study achieved a mean sleep of about 5 hours during their short breaks, although they reported needing 7.5 hours of sleep per night. In such situations, shift workers may be inclined to skip a meal such as breakfast, so as to allow more time for sleeping. This may explain why some studies have found that shift workers consume lower amounts of energy at "normal" breakfast and dinner times (eg, 37).

The effect of shift work on metabolic disorders

As noted above, shift workers' dietary habits may underlie their greater susceptibility to certain health problems. Shift workers report greater incidence of gastrointestinal problems (eg, irritable bowel syndrome, upper gastrointestinal dyspepsia, and peptic ulcer) (38). The higher rate of gastrointestinal upsets found among night workers may be due to changes in their processes of digestion, absorption, and storage of foods that are caused by varying work schedules (4, 39). Food absorption processes of the digestive system vary as a function of: (i) time of day [eg, meal intake in evening decreases gastric pH more than morning intake (40)]; (ii) decreased satiety in the evening (41); (iii) greater insulin resistance at night (9); and (iv) less gastrointestinal response after meals taken at night (42). Hence the absorptive system seems to be less "willing" to handle food at nighttime in accordance with studies in the field of chronopharmacology (43). Gastric problems may also be linked to frequent snacking (eg, on the night shift, as noted above). Health behavior is also likely to be affected by shift working. For example, there may be an increase in the consumption of coffee and other drugs that supposedly help maintain wakefulness at night, but which may also contribute to the development of gastric problems or other illnesses.

Shift working is also associated with metabolic disorders, particularly in relation to lipid and glucose intolerance. Karlsson et al (44) reported a cross-sectional survey of 27 485 people in Sweden in which they found that obesity, high triglycerides, and a low concentration of high-density lipid (HDL) cholesterol clustered more often among shift than day workers. Similarly, a comparison of day and shift workers found that a higher proportion of the latter had high triglyceride levels, low levels of HDL cholesterol, and abdominal obesity (45). Further evidence of the link between shift work and metabolic disorders come from a limited number of studies that have identified positive associations between shift work and incidence of diabetes (eg, 46, 47). More recently, a prospective cohort study followed a large sample of health workers over a four-year period and found that the risk of developing metabolic syndrome was strongly associated with working night shifts (48). These metabolic changes may play an important role in the higher prevalence of cardiovascular disease that is seen among shift workers (49). A number of other factors have also been associated with metabolic syndrome and cardiovascular disease (50) such as stress, disrupted circadian rhythms (see also 51), sleep debt, and health behavior (ie, less physical activity).

Various studies have demonstrated an association between shift work and the development or aggravation of obesity. One of the first to do so were Ballet et al (52) who showed that weight gain among a group of workers was greater after they began working nights. Subsequently, a large scale prospective cohort study observed a greater

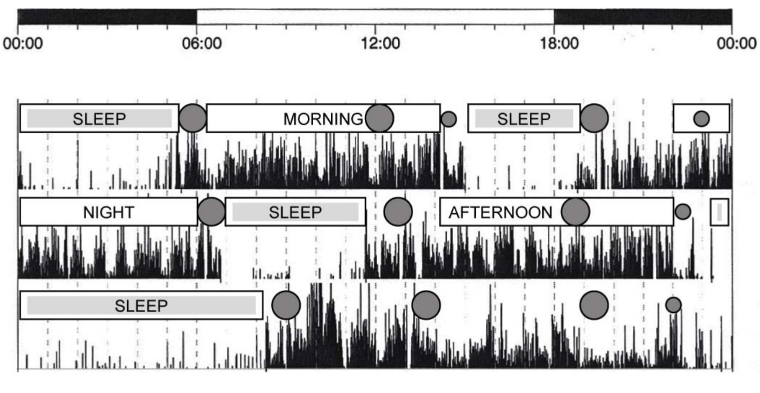

Figure 1. Actigraph (motion logger) output of the sleep–wake pattern of a female papermill shift worker on a rapidly rotating 8-hour schedule. [Large circle = complete meal, small circle = high quality snack]

increase in body mass index (0.12 per year) among both male and female shift workers employed for ≥5 years, as compared to a non-shift working control group (53). Niedhammer et al (54) also demonstrated a link between exposure to night work and the prevalence of excess weight and weight gain (>5 kilos) in a 10-year longitudinal study of nurses. In this study, the strength of the association increased as a function of age and seniority at work. Nakamura et al (55) also identified a greater tendency towards central obesity, as well as elevated cholesterol levels, among a group of Japanese male blue-collar compared with day workers. However, other studies have failed to verify the association between work schedules and the incidence of being overweight (56, 17).

While the majority of studies demonstrated an association between night work and weight gain, the causal factors underlying this association are still not well established. The restricted sleep that is commonly reported by shift workers is likely to be an important issue. Epidemiological evidence has established a link between obesity and durations of short sleep (57), an association that has also been observed in workers on an irregular shift schedule (58). [The possible mechanisms underpinning this link will be discussed in further detail below.] Another possible explanation of weight gain among shift workers is the effect that shift work has on lifestyle and health behaviors (eg, keeping fit). Geliebter et al (59) compared retrospectively the reported activity levels and eating behaviors of a group of 49 shift workers with 36 day workers. Those working late or night shifts reported greater weight gain in the past two years (4.2 kg versus 0.9 kg, no difference between genders). This increase was associated with an increase in food intake, a decrease in exercise, more napping, and a consequent reduction in total estimated energy expenditure.

Obesity is an important risk factor for various health problems that are more common among shift workers, such as cardiovascular illnesses, as well as for sleep problems (eg, sleep apnea syndrome). However, it should be remembered that obesity is only one risk factor for cardiovascular pathologies among many others that are more prevalent among shift workers (eg, smoking, lower socioeconomic status) (49). Thus caution is necessary when seeking to identify causal links between shift working and these various indices of health. For example, according to Boggild & Knutsson (50), obesity should be considered a confounding factor when seeking to establish a causal relation between shift/night work and cardiovascular diseases. In short, the link between shift work and several diseases [also cancer and impaired immune system, see Costa et al (60) discussion paper in this issue of the *Scandinavian Journal of Work, Environment & Health*] needs further study as many factors, including inadequate diet, can act as both direct causal risk factors and mediators of the relationship (28).

Pathways from poor diet to metabolic disorders

We now consider in greater detail the physiological and psychophysiological mechanisms that may underlie the impact of shift workers' diets. Eating at night and sleeping during the day is abnormal from a chronobiological perspective, causing disruption of the regulation system and thereby affecting the individual's appetite and metabolism (61).

Humans are predisposed to the promotion of glucose metabolism and fat storage in the daytime, when individuals normally eat, and glucose sparing and fat metabolism at night, when individuals normally fast. As a result of this predisposition, shift workers show a lowered glucose and lipid tolerance following the change from day to night working (61–64). For example, participants in a simulated shift work study were given a late evening meal (22:30 hours) and consequently exhibited elevated postprandial glucose and insulin responses (63). In addition to circadian disruption, shift workers commonly experience chronic sleep deprivation. Even relatively limited sleep restriction (two days with four hours of sleep versus two days with ten hours sleep) can result in substantially lowered glucose tolerance (65, 66). Recent evidence indicates that reduced sleep quality has similar effects, with three nights of slow-wave sleep suppression (with maintained total sleep time) producing a ≈30% decrease in insulin sensitivity (67).

Morgan et al (68) examined the impact of nocturnal eating on lipid intolerance using a laboratory-based constant routine protocol in which participants were isolated from all external time cues. They found that nocturnal eating and the length of time since waking were both positively associated with increased triglyceride concentrations. Similar indications of an association between nocturnal eating and increased triglyceride levels have been observed in other laboratory studies (69) and also among shift workers in the extreme conditions of the Antarctic (64). There is some evidence that the effects are more marked among males than females (70). A study of permanent night workers indicated that even after two years of regular night work (4–6 nights worked per week), glucose and insulin secretion rhythms were only partially adjusted to night work. This suggests that the negative metabolic consequences would be even greater for those working more rapidly rotating shifts. Thus elevated triglyceride levels are likely to be present from the first night shift and therefore night workers will frequently be exposed to this potentially harmful condition. It has been suggested that light treatment could be used as a countermeasure of increased triglyceride at night (71). [See the paper of Pallesen et al (72) on measures to counteract the negative effects of night work in this issue.]

A recent study examined levels of homocysteine among shift workers after an overnight fast (73).

Homocysteine is an amino acid in the blood that is thought to be associated with an increased risk of coronary heart disease (74). Higher homocysteine levels were detected among shift workers who were >40 years and had been experiencing sleep problems. Homocysteine shows a circadian nocturnal peak that is elevated by the consumption of animal protein meals taken at night. Thus it may be concluded that elevated night-time levels of homocysteine – together with reduced glucose and lipid tolerance at night and following sleep deprivation – are important cardiovascular risk factors for shift workers.

Sleep deprivation

Obesity is the outcome of non-homeostatic eating or energy balance (ie, when energy accumulated from protein, fat, carbohydrates, or alcohol exceeds energy expenditure). The regulation and modification of food intake is based on the interpretation of endogenous signals (eg, from the body clock, the gut, etc) as well as exogenous signals from the environment. Sleep dept, circadian disruption, and chronic stress can affect the endogenous signals and thereby contribute to failures in the homeostatic control of food intake (75). For example, laboratory studies have shown that partial sleep deprivation causes changes in two of the hormones involved in the regulation of food intake, namely, ghrelin (increased after sleep deprivation) and leptin (decreased after sleep deprivation), prompting an increase in subjective appetite (69). Similarly, a recent study showed that moderate sleep deprivation leads to an increase in the consumption of energy from snacks with a (slightly) higher carbohydrate content (76). Reduced leptin levels have also been linked to the misalignment of behavioral rhythms and endogenous circadian rhythms, an effect that was shown to be independent of the impact of impaired sleep (77). It is also worth noting that, under normal circumstances, leptin levels increase in the late evening, prompting feelings of satiety. Serotonin levels decrease during early-morning hours and prompt feelings of hunger. This is part of a circadian pattern that promotes nocturnal resting and diurnal eating (78). Understanding of this mechanism could be promoted among shift workers to reduce food intake late at night or even abstain from food at night, especially after 03.00 hours.

Circadian disruption

Laboratory evidence suggests that, like light and sleep, food intake can act as a "zeitgeber" (ie, it can influence the timing of the body clock) (79). Participants were given a high carbohydrate meal either in the evening or in the morning, and then underwent a "constant routine" (ie, they were isolated from all exogenous time cues). The evening condition produced a phase advance of ≈1 hour in the circadian rhythm of body temperature, together with a smaller advance (15 minutes) of the circadian phase of heart rate. The authors concluded that eating has a substantial influence as a zeitgeber on peripheral clocks but only a weak influence on the central clock or suprachiasmatic nucleus (SCN) in the brain. [However, evidence from rodent studies suggests that severe caloric restriction may influence the SCN clock, as a result of the impact on metabolic cues, even when an opposing light–dark cycle is present (80).] It has subsequently been proposed that disruption of these peripheral circadian oscillators may be involved in the development of obesity, type II diabetes, and metabolic syndrome (81). If this is the case, then it suggests that circadian disruption should be minimized when working nights, through the attempted maintenance of a (relatively) diurnal rhythm. This could be encouraged by keeping the same meal times across the shift cycle (82) and avoiding eating, or at least restricting energy intake, between midnight and 06.00 hours.

In addition to the endogenous factors underlying failed homeostatic control of food intake, there are a range of possible exogenous contributors. One is the absence of social influence on eating (eg, eating with family). Another is the 24-hour availability of cheap, tasty and energy-dense food products. When living "around the clock", eating may be promoted, permitted, and facilitated anywhere, at anytime. This can encourage snacking or "grazing behavior" (ie, eating spontaneously and continuously instead of maintaining a pattern of regular and planned eating events).

Diet and mental performance

The relationship between food, sleepiness, and performance is not fully understood. Recent research reveals that the regulation of energy balance depends on the precise coordination of multiple peripheral and central systems. Complex behaviors such as learning are likely to be affected by orexigenic hypothalamic neuropeptides as well as wakefulness and appetite (83). Additionally, the more well-known regulatory systems also seem to play important roles. For example, it is known that blood glucose levels increase following the consumption of a meal (postprandial) and return to pre-meal levels later due to the release of insulin. It has been postulated that the relative change in blood glucose levels is the key factor affecting postprandial performance (84). However, the failure to adequately absorb and metabolize glucose may only mildly interfere with brain activity (eg, adults undertaking an overnight fast maintain glucose levels of >5 mmol/l, while detrimental effects on performance appear around levels of 3 mmol/l). Nevertheless, the changes in mood related to reduced blood sugar (increase in hunger and irritation, lack of energy, sensitivity to stress, etc) might negatively affect performance of many tasks that demand vigilance and concentration.

The so-called “post-lunch dip” in performance is independent of food intake, although performance will deteriorate further if a meal is taken at lunch time (85). Tasks involving sustained attention are most sensitive in this respect, with larger meals producing more frequent lapses of attention (84). More generally, alertness decreases following food intake (86–88), with objective signs of sleepiness commonly peaking 3.5 hours after ingestion (89). Carbohydrate-rich meals produce greater decrements in mental performance (in contrast to physical performance) and increase sleepiness as compared to fat-rich meals (90). The effects of food ingestion on sleepiness occur with equal magnitude during day- and nighttime (91). Nevertheless, it should be noted that, compared to circadian effects on sleep and performance, the effects of macronutrient differences and the postprandial response are relatively weak (92).

Holmbäck and colleagues (42, 91) have examined the question of whether night workers should fast or feed during their nightshift. Seven males were kept awake in the laboratory for 24 hours. In the fasting condition, participants received all their food during the daytime, while, in the non-fasting condition, the same amount of food was distributed evenly over the 24-hour period. Although performance was unaffected by diet, subjective ratings of sleepiness were significantly elevated and subjective energy levels were lower at night in the fasting condition (93).

Discussion

The earlier discussion of table 1 indicated that the overall picture obtained from studies of shift workers’ dietary habits is complex, with numerous contradictory findings. It is difficult to compare results between the relatively few studies and also to draw conclusions, due to limits in design and the use of less-valid dietary assessment methods. The methods for quantifying the amounts eaten varied and were not always precise. For example, a variety of means (eg, standard portion household measures, photos, drawings) were used to report consumed amounts, making it impossible to convert volumes to weights (eg, portions of pasta, rice, mashed potatoes). Instructions for respondents explaining how to report details on fiber content of bread, fat composition in spread, or fat content in milk or cheese, among others, varied between studies. Similarly, food frequency questionnaires and nutrient databases also varied between studies, with information on the latter and data treatment lacking in many studies. The temporal distribution of eating or “meal patterns” among shift workers is of particular interest, but many studies failed to clearly define the criteria used for classifying eating events. Moreover, the classification schemes often failed to adequately reflect the nutritional properties of what was eaten. For example, classifications may have simply reflected the time of day that a meal was taken (eg, breakfast, lunch, or dinner) or been based on the type of meal that was taken (eg, main meal, between meal, light meal, hot meal, or snack). Comparisons between findings were also hindered by the fact that the author(s) performed classification in some studies, while in others the participants did it themselves.

An alternative way of classifying eating events is to assess the type of food items that are consumed. The nutrient profiles of foods originating from animals and plants may be characterized in terms of content of water- and fat-soluble vitamins, minerals, trace elements, and other bio-active compounds (eg, antioxidants), and additionally protein and fat quality. A variety of foods are needed to provide an organism with all the essential nutrients that are available in energy-yielders (ie, protein, fat, and carbohydrates). According to this rationale, we suggest some classifications in table 2.

By recording the frequency of each type of meal and snack in this way, information is obtained regarding the nutritional profiles of the eating events. The eating event is classified at the “highest” possible level and the terminology may be tailored to fit the purpose of the study (eg, the researcher can make a distinction between complete meal with or without a sweet dessert).

The choice of design for future studies in this area should be determined by the intended aims of the researchers. *Food consumption studies* are restricted to gathering only data on the ingestion of foods, energy, and nutrients. The data are then evaluated by comparison with nutritional recommendations for participants based on age, gender, and level of physical activity. In this way, between-group comparisons may be conducted in order to judge the “healthiest” versus “poorest” eating habits. However, such studies do not provide information about the metabolic state of the participants. *Nutrition surveys* are more comprehensive and involve the assessment of food consumption in combination with one or more of the following parameters: (i) anthropometric measurements (ie, body weight, waist/hip ratio, body mass index); (ii) biochemical analysis (ie, serum lipids, glucose clearance); (iii) clinical signs (hair, mouth, muscles); and (iv) functional or cognitive tests (94).

One of the most important challenges for researchers is to identify when shift workers eat with respect to their work hours and circadian rhythms. This is needed in order to address the core question of when and what night

Table 2. Suggested classification of food events

Classification	Composition
Complete meal	Animal foods + starchy and/or protein-rich vegetable foods (ie, cereals, rice, pasta, potatoes, roots, lentils or leguminous crops like dried peas and beans) + non-starchy vegetable foods fruits or vegetables or berries
Incomplete meal	Complete Meal lacking fruits, vegetables or berries
Vegetarian meal	Beans, peas or lentils + cereals + roots or fruits or vegetables or berries
High-quality snack	Consumption of foods from just one of the above food groups (eg, a glass of plain yoghurt, an apple, a slice of cheese).
Low-quality snack	Consumption of alcohol or a food product with added sugar
Mixed-quality snack	One high quality snack combined with alcohol or foods with added sugars (eg, apple and a soft drink, piece of chocolate and an orange)

workers should eat so as to avoid inducing metabolic disturbances and optimize wakefulness and performance in order to avoid accidents. The impact of eating per se (ingestion of energy) and also eating certain macronutrients (fats, carbohydrates, protein), in the wrong phase of the circadian rhythm also needs further investigation. Another important area for future study is the metabolic consequences of large day-to-day variations in the timing of meals commonly experienced by shift workers. And finally, there is a need to examine further how shift work affects appetite and the regulation of food intake and its longer term effects on body weight.

It is strongly recommended that employers take steps to develop a nutrition management strategy at the workplace. This will involve recognizing that food intake is strongly influenced by motivational factors as well as external factors such as the availability of foods and beverages and having the time to eat in a relaxing context. Hence the strategy must consider not only how the body copes with irregular eating habits, but also how those habits are shaped by irregular work hours. Nutrition management needs to consider the factors that influence both the time at which the individual chooses to eat and the meal content that is chosen or preferred. Recommendations for a dietary regime that are based solely on what best suits the circadian rhythm of our digestive and metabolic processes will be of little practical use if they interfere with the management of fatigue or special energy requirements at work. A nutrition management strategy may also seek to improve individuals eating behavior. This will need to take into account the attitudes and values of both employees and management. The strategy also needs to identify shift workers' perceived barriers to changing their lifestyle and eating behavior (26).

In summary, it is clear that more research is needed in order to understand more fully the relationship between shift workers and their diets and the effects on their metabolism and performance. As noted above, the methodological problems inherent in some of the previous research have hampered the development of appropriate advice for shift workers and their employers. Nevertheless, notwithstanding the substantial gaps in our current knowledge, it is still possible to identify some broad guiding principals from the research conducted to date that may be included in nutrition management strategies. It is important to note that these guidelines are to be considered in parallel with appropriate fatigue management strategies. These guidelines – targeted directly at the individual or the employer – are appropriate not only for shift workers but also other populations thus some general guidelines are listed first.

General guidelines

- Avoid eating, or at least restrict energy intake, between midnight and 06.00 hours, and try to eat at the beginning and end of the shift.
- Avoid "large meals" (>20% of daily energy intake) 1–2 hours prior to the main daily sleep episode.
- Provide a variety of food choices: complete or vegetarian meals and high-quality snacks are recommended. Avoid foods and beverages classified as low-quality snacks.
- Provide appropriate dining facilities that, for example, allow a meal to be eaten away from the workplace, with colleagues, in as pleasant a surrounding as possible.
- Maintain a healthy lifestyle with exercise, regular meal times, and good sleep hygiene when not working.

Specific guidelines for shift work

- Eat breakfast before day sleep to avoid wakening due to hunger.
- Stick as closely as possible to a normal day and night pattern of food intake (95). See for example the Nordic Nutrition Recommendations (96).
- Divide the 24-hour intake into eating events with three satiating meals each contributing 20–35% of 24-hour intakes. The higher the energy needs, the more frequent the eating should be.
- Avoid over-reliance on (high-energy content) convenience foods and high-carbohydrate foods during the shift. Instead choose vegetable soups, salads, fruit salads, yoghurt, wholegrain sandwiches, cheese or cottage cheese (topped with slices of fruits), boiled

egg, nuts, and green tea (promoting antioxidant activity), although this may not be palatable to some.

- Design shift schedules so as to allow adequate time between shifts for sleep, meal preparation, amongst others, avoid quick returns.
- Avoid sugar-rich products such as soft drinks, bakery items, sweets, and non-fiber carbohydrate foods (high glycemic load) like white bread.

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