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Circadian Preference, Work Schedules, Adiposity and Eating Patterns among Adults in Tamil Nadu, India

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ABSTRACT: Evening chronotype has been associated with adverse dietary behaviours and metabolic health outcomes in adults. However, evidence linking circadian preference, social jetlag, and occupational work schedules with adiposity, dietary intake, and chrononutrition remains limited among Indian adults. This study examined these associations in 720 adults aged 25–50 years from Tamil Nadu, India. Data on adiposity, work schedules, circadian preference, sleep, diet, and lifestyle were collected using standardized measurements, established, and expert-reviewed questionnaires. Correlation analyses and multivariable linear regression examined associations between study variables. Higher rMEQ scores were independently associated with lower BMI ($B = -0.240$, 95% CI: −0.376 to −0.105; $P < 0.001$) and waist circumference ($B = -0.660$ cm, 95% CI: −0.991 to −0.329; $P < 0.001$). Social jetlag was positively correlated with diastolic blood pressure ($\varrho = 0.130$, $P < 0.001$). Occupational schedules were associated with chrononutrition differences, including more frequent late-night snacking among night-shift workers (40.4%), later first meals and shorter eating windows among rotating-shift workers ($P < 0.001$ for both). Compared with day-shift workers, rotating-shift work and non-employment were associated with higher waist circumference ($B = 3.321$ cm, 95% CI: 0.374 to 6.268; $P = 0.027$; $B = 3.376$ cm, 95% CI: 0.424 to 6.328; $P = 0.025$, respectively). Energy and macronutrient intakes were broadly comparable across schedules, although selected nutrient differences were observed. Greater morningness was independently associated with lower BMI and waist circumference, whereas occupational work schedule was not independently associated with BMI. Occupational schedules were more strongly related to food timing than energy or macronutrient intake.

INTRODUCTION

Work schedules have changed considerably with the expansion of the 24-hour economy, and many adults now work outside conventional daytime hours. Shift work, permanent night work, rotating schedules, and extended working hours are common across a range of occupational sectors (International Labour Organization, 2022; Silva & Costa, 2023). Although these schedules are essential for maintaining continuous services and economic activity, increasing evidence suggests that working outside conventional daytime hours is associated with adverse metabolic health outcomes (Hemmer et al., 2021; Silva & Costa, 2023). Observational studies and meta-analyses have reported associations between shift work and overweight or obesity, indicating stronger associations with night work and abdominal obesity (Proper et al., 2016; Liu et al., 2018; Sun et al., 2018). These relationships are biologically plausible because working at night can disrupt the normal coordination of sleep, activity, food intake, and metabolic processes (Antunes et al., 2010).

Circadian disruption is considered an important factor in the relationship between occupational schedules and metabolic health. The circadian system coordinates daily rhythms in sleep–wake behaviour, hormonal secretion, energy metabolism, and other physiological processes. When externally imposed work and sleep schedules are poorly aligned with endogenous circadian timing, this coordination may be disturbed, potentially affecting metabolic homeostasis and cardiometabolic health (Kervezee et al., 2020; Boivin et al., 2022). However, responses to the same occupational schedule may differ between individuals. Chronotype, which reflects an individual's preference for the timing of sleep and daily activity, may influence adaptation to different occupational schedules. Previous research suggests that the relationship between chronotype and shift timing may be relevant to sleep and other health outcomes among shift workers (Vetter et al., 2015).

Social jet lag is a measure of the discrepancy between sleep timing on socially constrained days and free days (Wittmann et al., 2006; Roenneberg et al., 2012). Both chronotype and social jet lag have been investigated in relation to obesity and metabolic health. In particular, evening preference has been associated with less favourable metabolic and behavioural profiles, although the strength of these associations varies across populations (Baidoo & Knutson, 2023). Evening chronotype has also been associated with less favourable dietary patterns, including differences in fiber, fruit and vegetable, and plant-protein intake and higher dietary energy density (Zuraikat et al., 2021). Examining chronotype together with occupational schedules may therefore provide information that cannot be obtained from work schedules alone.

Circadian characteristics may also be related to obesity through differences in everyday eating behaviour. The timing and regularity of food intake are increasingly recognised as relevant components of metabolic health. Late or irregular meals and night-time eating may interact with circadian biology and influence glucose regulation, appetite, and energy metabolism (McHill & Wright, 2017; Basolo et al., 2021). These observations have contributed to the development of chrononutrition, which examines the relationship between the timing and distribution of food intake and circadian biology (Flanagan et al., 2021; Raji et al., 2024). Recent evidence further suggests that meal timing may be relevant to body-weight regulation and metabolic health (Reytor-González et al., 2025). Occupational schedules may be particularly important in this context because working during the evening or night can alter the timing and distribution of meals and may increase the likelihood of eating outside conventional daytime hours (Hemmer et al., 2021).

These factors are closely interconnected. Occupational schedules may be related to sleep and meal timing, while individual chronotype may influence how a person adapts to a particular schedule. Dietary intake, physical activity, and other lifestyle behaviours may also be related to differences in body weight. Despite growing interest in these relationships, occupational schedules, chronotype, social jetlag, eating behaviour, and obesity have often been examined separately rather than within an integrated framework (Golding et al., 2022). Furthermore, much of the available evidence has been generated in high-income settings, with comparatively limited evidence from Indian populations, where occupational conditions, dietary practices, socioeconomic circumstances, and lifestyle behaviours may differ.

Although previous studies have examined circadian preference, social jetlag, occupational work schedules, and dietary behaviours in relation to metabolic health, evidence on their combined associations with adiposity and chrononutrition remains limited among Indian adults. Circadian preference may be associated with differences in adiposity, while occupational work schedules may influence eating behaviours, including meal timing and late-night snacking. However, these relationships have not been sufficiently characterised within an integrated framework in Indian populations. Therefore, the present study aimed to examine the associations of circadian preference and occupational work schedules with adiposity, sleep characteristics, dietary intake, and chrononutrition among adults in Tamil Nadu, India. We hypothesised that greater morningness would be associated with more favourable adiposity profiles and that eating patterns and dietary intake would differ across occupational work schedules.

MATERIALS AND METHODS

Design and study population

This community-based cross-sectional study was conducted among adults aged 25–50 years residing in Tamil Nadu, India. To include participants from different geographical regions of Tamil Nadu, four districts were purposively selected: Krishnagiri in the north, Kallakurichi in the east, Coimbatore in the west, and Virudhunagar in the south.

Data were collected between April 2026 and August 2026. Within each district, urban and semi-urban localities were identified, and eligible adults were approached in person at households, workplaces, educational institutions, and community gathering

points by trained investigators. Adults aged 25–50 years residing in the selected districts were eligible to participate irrespective of employment status. Individuals with diagnosed endocrine disorders, chronic systemic diseases affecting metabolism, psychiatric disorders that could substantially influence sleep, eating behaviour, or metabolic status, pregnancy or lactation, or current pharmacological treatment for obesity were excluded. Potential participants were screened for the age criterion and exclusion criteria at first contact, and those eligible and willing were enrolled at the same or a subsequent visit. All participants provided written informed consent before enrolment. The number of individuals approached but not enrolled was not systematically recorded, so a response rate cannot be calculated. Because enrolment depended on availability and willingness to participate, the sample was not probability-based, and adults who were more health-aware or more available during data-collection hours may be over-represented. The final analytical sample consisted of 720 participants, including 649 employed and 71 non-employed adults.

The sample size for the prevalence component of the study was estimated using the single-population-proportion formula, $n = Z^2P(1-P)/d^2$ (Lwanga & Lemeshow, 1991), where n represents the required sample size, Z the standard normal deviate corresponding to the confidence level, P the expected prevalence, and d the absolute precision. Assuming an overweight or obesity prevalence of 40%, a 95% confidence level (Z = 1.96), and 5% absolute precision, the minimum required sample was 369 participants. The final sample of 720 exceeded this requirement. No separate power calculation was performed for the association analyses. The overall sample provided approximately 55 observations per fitted predictor parameter in the 13-parameter regression models. However, the rotating-shift (n = 55) and non-employed (n = 71) groups were relatively small, resulting in less precise estimates for these groups.

Data collection

Data were collected by trained investigators using standardized anthropometric measurements and interviewer-administered questionnaires. Circadian preference, sleep quality, and physical activity were assessed using the rMEQ (Adan & Almirall, 1991), PSQI (Buysse et al., 1989), and IPAQ-SF (Craig et al., 2003). Dietary intake (FFQ and 24-hour recall), work schedule, and chrononutrition items were developed by the investigators from the literature, and their content validity was established by five subject experts and a biostatistician. Instruments were administered in Tamil and English. Energy and nutrient intakes were calculated using Dietcal.

Before the main survey, the investigator-developed questionnaire was pilot-tested among 32 adults from the target population to assess its clarity, comprehension, and feasibility. Minor modifications were made based on participant feedback. Internal consistency was evaluated using Cronbach's alpha, which yielded a coefficient of 0.70. Night-time screen use was recorded as the average number of hours per day spent using electronic screen-based devices during the night-time period.

Occupational work schedule

Employment status and occupational work schedules were assessed using a structured, interviewer-administered questionnaire. Employed participants were classified into three categories based on their self-reported usual working schedules: day-shift, permanent night-shift, and rotating-shift workers. Day-shift workers were defined as individuals whose working hours predominantly fell between 06:00 and 18:00 hours. Permanent night-shift workers were defined as individuals who regularly worked during night-time hours (18:00–06:00 hours) without routinely alternating between day and night shifts. Rotating-shift workers were defined as individuals whose work schedules alternated between daytime, evening, and/or night-time shifts according to their occupational duty rosters. Classification was based on the usual pattern of employment rather than an objectively verified record of working hours. Participants who were not employed, including homemakers and unemployed individuals, were classified separately as "Others" in analyses involving the entire study population.

Determination of Circadian Preference and Social Jetlag

Circadian preference was assessed using the Reduced Morningness–Eveningness Questionnaire (rMEQ; Adan & Almirall, 1991), which evaluates preferred waking time, bedtime, peak alertness, and daily activity preference. Scores range from 4 to 25, with higher scores indicating greater morning preference. Circadian preference is therefore defined here as self-reported behavioural preference for the timing of sleep, waking, and peak alertness, not as endogenous circadian phase; objective markers such as dim-light melatonin onset and actigraphy were not assessed.

Because the conventional rMEQ cut-offs were unevenly distributed in this population, participants were classified using sample-specific tertiles of the rMEQ score (33rd and 66th percentiles): ≤18 indicating an evening tendency, 19–20 intermediate, and ≥21 a morning tendency. These categories are sample-relative rather than absolute and are not equivalent to the conventional definite morning or evening types; as the tertile boundaries differ by only one to two points, participants close to a boundary may not differ meaningfully in circadian preference. The tertile classification was used for descriptive and group comparisons only, whereas the rMEQ score was analysed as a continuous variable in all regression models, so the cut-offs do not influence the reported coefficients.

Social jetlag was calculated as the absolute difference between the midpoint of sleep on workdays (MSW) and on free days (MSF), $|MSF - MSW|$, where the sleep midpoint is the time halfway between self-reported sleep onset and wake-up time (Roenneberg et al., 2012). It was expressed in hours, with 0 h indicating identical sleep timing on both day types and higher values greater discrepancy. Because the absolute value was used, the measure captures the magnitude but not the direction of this discrepancy; sleep timing was not corrected for sleep debt, and for permanent night-shift workers the workday–free-day contrast reflects an inverted rather than a delayed schedule. These features limit comparability with studies using direction-specific or sleep-corrected definitions.

Dietary and chrononutrition assessment

Dietary intake was assessed using two instruments serving distinct purposes. A semi-quantitative food frequency questionnaire recorded the usual frequency of consumption of locally relevant food groups over the preceding three months and was used only to characterise habitual food-consumption patterns; it was not used to derive quantitative energy or nutrient values. All quantitative estimates of energy and nutrient intake reported in this study were obtained from a single interviewer-administered 24-hour dietary recall. Intake was recorded separately for breakfast, lunch, dinner, and snacks, with portion sizes estimated using standard household measures (cups, spoons, and ladles) and locally familiar serving references. Energy, macronutrient, and micronutrient values were computed using Dietcal software, which draws on Indian food composition data. Because intake was assessed on a single day, the values reflect consumption on that day rather than habitual intake, and within-person day-to-day variation could not be quantified.

Chrononutrition behaviours were assessed using a structured questionnaire. Information was obtained on breakfast consumption, first-meal timing, lunch timing, dinner timing, last-meal timing, meal frequency, meal regularity, daily eating-window duration, meal skipping, and late-night snacking. Breakfast skipping was defined as the habitual omission of breakfast on most days of the week, while meal skipping was categorised as no, sometimes, or yes according to the participant's reported usual pattern. Meal regularity was assessed by comparing usual meal times across weekdays and weekends. Late-night snacking was defined as food consumption after 21:00 hours or within two hours before habitual bedtime. The daily eating window was calculated as the time interval between self-reported usual breakfast and dinner times on a typical day, with meal times converted to decimal hours for analysis. Snack timing was recorded separately and was not included in this calculation. Therefore, the operationally defined eating window represented the interval between the two main meal occasions rather than the complete duration between the first and last caloric intake.

Sleep assessment

Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), a validated instrument for evaluating subjective sleep quality during the preceding month (Buysse et al., 1989). The PSQI comprises seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Component scores were summed to obtain a global score ranging from 0 to 21, with higher scores indicating poorer sleep quality. A global PSQI score >5 was considered indicative of poor sleep quality.

Participants additionally reported their habitual bedtime, wake-up time, sleep duration, and daytime napping patterns on workdays and free days. The global PSQI score was examined as a continuous variable in the multivariable regression analyses.

Physical activity

Physical activity was assessed using the International Physical Activity Questionnaire–Short Form (IPAQ-SF) (Craig et al., 2003). Participants reported the frequency and duration of vigorous-intensity activity, moderate-intensity activity, walking, and sedentary behaviour during the preceding seven days.

Physical activity was expressed as total metabolic equivalent of task minutes per week (MET-min/week) according to the IPAQ scoring protocol. Participants were classified as having low, moderate, or high physical activity for descriptive analyses, while total MET-min/week was examined as a continuous variable in the multivariable regression analyses.

Anthropometric and clinical parameters

Anthropometric measurements were obtained by trained investigators using standardized procedures. Body weight was measured to the nearest 0.1 kg using a calibrated digital weighing scale, and height was measured to the nearest 0.1 cm using a stadiometer while participants stood upright without footwear. Body mass index (BMI) was calculated as weight in kilograms divided by height in metres squared (kg/m²).

According to Asian-specific BMI cut-offs, participants were classified as underweight (<18.5 kg/m²), normal weight (18.5–22.9 kg/m²), overweight (23.0–24.9 kg/m²), Grade 1 obesity (25.0–29.9 kg/m²), or Grade 2 obesity (≥30.0 kg/m²) (Misra et al., 2009).

Waist circumference was measured midway between the iliac crest and the lower margin of the last palpable rib using a non-elastic measuring tape. Hip circumference was measured at the point of maximum gluteal circumference. Waist-to-hip ratio (WHR) was calculated as waist circumference divided by hip circumference, whereas waist-to-height ratio (WHtR) was calculated as waist circumference divided by height. Waist circumference was categorised using Asian Indian action levels (Misra et al., 2006): normal (<78 cm in men, <72 cm in women), Action Level 1 (78–89 cm in men, 72–79 cm in women), and Action Level 2 (≥90 cm in men, ≥80 cm in women). Central obesity was defined as Action Level 2 (≥90 cm in men, ≥80 cm in women).

Body fat percentage was assessed using the Omron HBF-306C Handheld Body Fat Monitor (Omron Healthcare Co., Ltd., Kyoto, Japan), which estimates body composition using bioelectrical impedance analysis. Participants were instructed to avoid vigorous physical activity, alcohol consumption, and large meals before measurement to minimize variations related to hydration status. BMI was considered the primary adiposity outcome, while waist circumference and body fat percentage were considered secondary adiposity measures.

Blood pressure was measured using an Omron automated blood pressure monitor after participants had rested in a seated position for 5 min. Three consecutive measurements were obtained, and the average of the three readings was used for analysis. Systolic and diastolic blood pressure were recorded in mmHg.

Potential confounding variables

Potential confounding variables were selected based on their relevance to circadian characteristics, occupational work schedules, and adiposity. Age, sex, social jetlag, average sleep duration, sleep quality, breakfast skipping, dietary energy intake, and physical activity were considered in the adjusted analyses. Sleep quality was represented by the PSQI global score, dietary energy intake was derived from the 24-hour dietary recall, and physical activity was expressed as total MET-min/week. These variables were included as covariates in the multivariable models to account for their potential influence on the associations of circadian preference and occupational work schedule with adiposity.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics, Version 28.0 (IBM Corp., 2021) and JASP, Version 0.16 (JASP Team, 2022). Continuous variables were expressed as mean ± standard deviation (SD) or median (interquartile range [IQR]), as appropriate, and categorical variables as frequencies and percentages. Normality was assessed using the Shapiro–Wilk test. Differences between two independent groups were examined using the independent-samples *t*-test or Mann–Whitney *U* test, whereas comparisons among three or more groups were performed using one-way analysis of variance (ANOVA) with Tukey's post-hoc test or the Kruskal–Wallis test, as appropriate. Categorical variables were compared using Pearson's chi-square test or Fisher's exact test, and correlations were examined using Pearson's or Spearman's correlation coefficients, as appropriate.

The overall analytical sample comprised 720 participants. For analyses involving the entire study population, occupational status was classified into four categories: day-shift, permanent night-shift, rotating-shift, and non-employed, with day-shift workers serving as the reference category. The non-employed category included homemakers and unemployed individuals. Analyses comparing occupational work schedules were restricted to the 649 employed participants. Chronotype distribution across

occupational work schedules within BMI categories was examined among employed participants using Pearson's chi-square test or Fisher's exact test, as appropriate. Cramér's V was reported as a measure of effect size.

Multivariable linear regression was used to examine the independent associations of circadian preference and occupational status with BMI, waist circumference, and body fat percentage in the overall sample (N = 720). Covariates were selected a priori on the basis of established associations with adiposity and with circadian timing, rather than by stepwise or data-driven selection. Age and sex were included as fundamental demographic determinants of body composition, and occupational schedule because shift work imposes the external constraint on sleep and meal timing that motivated this study. Social jetlag, average sleep duration, and PSQI global score were included to distinguish the contribution of circadian preference from those of sleep-timing discrepancy, sleep quantity, and sleep quality. Breakfast skipping and dietary energy intake were included to account for behavioural and quantitative dimensions of intake respectively, and physical activity to account for energy expenditure. The same covariate set was retained across all three outcomes to permit direct comparison of coefficients.

All multivariable regression models included 13 predictor parameters excluding the intercept: rMEQ score, occupational status (three indicator variables, with day-shift workers as the reference category), age, sex (female as the reference category), social jetlag, average sleep duration, PSQI global score, breakfast skipping (two indicator variables, with no skipping as the reference category), dietary energy intake, and physical activity. Dietary energy intake was scaled per 100 kcal/day and physical activity per 100 MET-minutes/week to yield interpretable coefficient magnitudes; rMEQ score, age, social jetlag, sleep duration, and PSQI global score were entered in their original units. Unstandardised coefficients (B) indicate the mean difference in the outcome per one-unit increase in a continuous predictor, or relative to the reference category for a categorical predictor, with all other covariates held constant. The 95% confidence interval indicates the range of values compatible with the data, and intervals excluding zero correspond to $P < 0.05$. Model assumptions were assessed by inspection of standardised residual histograms and normal probability plots, and multicollinearity by variance inflation factors, which indicated no problematic collinearity among the model predictors. A sensitivity analysis restricted to employed participants (n = 649) was performed using the same BMI model, excluding the non-employed category.

Ethical considerations

The study protocol was approved by the Institutional Human Ethics Committee of the PSG Institute of Medical Sciences & Research (approval number: PSG/IHEC/2026/Appr/Exp/329) before participant recruitment. All study procedures complied with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all participants before enrolment.

RESULTS AND DISCUSSION

Participant characteristics

A total of 720 adults were included in the study, with a mean age of 40.30 ± 6.15 years; 367 were males and 353 were females. Of the total sample, 649 participants were employed and 71 were non-employed. Among employed participants, 322 (49.6%) worked day shifts, 272 (41.9%) permanent night shifts, and 55 (8.5%) rotating shifts, with no difference in shift distribution by sex (Table 1). Males were older, were more likely to be employed, and reported more years of shift work than females. BMI category, waist circumference category, body fat percentage, and diastolic blood pressure differed by sex. Chronotype distribution was comparable between males and females (P = 0.741), whereas social jetlag and average sleep duration differed significantly. Sleep quality and physical activity did not differ by sex.

Table 1. Sociodemographic, Occupational, Anthropometric, and Clinical Characteristics of the Study Participants According to Gender (N = 720)

Domain	Characteristic	Overall Population (N = 720)	Male (n=367)	Female (n=353)	P-value
Sociodemographic	Age (years)	40.30 ± 6.15	41.09 ± 6.05	39.47 ± 6.15	<0.001

	Employment Status, n (%)				
	Employed	649 (90.1)	344 (93.7)	305 (86.4)	0.025
	Homemaker	48 (6.7)	15 (4.1)	33 (9.3)	
	Unemployed	23 (3.2)	8 (2.2)	15 (4.2)	
Occupational	Work Shift, n (%)				
Employed participants (n = 649)	Day Shift	322 (49.6)	164 (47.7)	158 (51.8)	0.317
	Night Shift	272 (41.9)	153 (44.5)	119 (39.0)	
	Rotating Shift	55 (8.5)	27 (7.8)	28 (9.2)	
	Years of Shift Work	7.9 ± 4.5	8.8 ± 4.6	6.9 ± 4.2	<0.001
Anthropometric	BMI Category, n (%)				
	Underweight	19 (2.6)	5 (1.4)	14 (4.0)	<0.001
	Normal weight	301 (41.8)	130 (35.4)	171 (48.4)	
	Overweight	292 (40.6)	170 (46.3)	122 (34.6)	
	Obesity Grade 1	81 (11.2)	54 (14.7)	27 (7.6)	
	Obesity Grade 2	27 (3.8)	8 (2.2)	19 (5.4)	
	Waist Circumference Category, n (%)				
	Normal	334 (46.4)	198 (54.0)	136 (38.5)	<0.001
	Action Level 1	233 (32.4)	111 (30.2)	122 (34.6)	
	Action Level 2	153 (21.3)	58 (15.8)	95 (26.9)	
	Waist-to-hip Ratio	0.872 ± 0.097	0.869 ± 0.092	0.875 ± 0.101	0.415
Clinical	Body Fat (%)	28.40 ± 7.77	27.42 ± 7.82	29.35 ± 7.61	<0.001
	Systolic Blood Pressure (mmHg)	124.48 ± 15.56	125.55 ± 14.05	123.36 ± 16.94	0.06
	Diastolic Blood Pressure (mmHg)	81.55 ± 9.8	79.76 ± 8.99	83.41 ± 10.27	<0.001
Circadian	Chronotype, n (%)				
	Morningness	295 (41.0)	149 (40.6)	146 (41.4)	0.741
	Intermediate	221 (30.7)	108 (29.4)	113 (32.0)	
	Eveningness	204 (28.3)	110 (30.0)	94 (26.6)	
	Social Jetlag (hours)	3.35 ± 3.39	2.78 ± 3.62	3.95 ± 3.03	<0.001
Sleep	Average Sleep Duration (h/night)	7.66 ± 2.54	7.86 ± 1.81	7.45 ± 3.11	0.029

	Sleep Quality, n (%)				
	Good sleep quality (PSQI ≤5)	426 (59.2)	205 (55.9)	221 (62.6)	0.077
	Poor sleep quality (PSQI >5)	294 (40.8)	162 (44.1)	132 (37.4)	
Lifestyle	Physical Activity (MET-min/week)	1931.01 ± 731.25	1968.37 ± 736.57	1892.16 ± 724.68	0.162

Footnotes: Values are presented as n (%) or mean ± SD. Characteristics are reported for the total study population (N = 720). Work-shift variables were assessed among employed participants only (n = 649); therefore, their percentages and summary statistics are based on the employed population. Circadian preference categories were defined using sample-specific rMEQ score cut-offs: evening tendency (≤18), intermediate tendency (19–20), and morning tendency (≥21). These categories reflect relative morningness–eveningness tendencies within the study population and should not be interpreted as conventional chronotype classifications. Meal times were converted to decimal hours for analysis. SD, standard deviation. For categorical variables with more than two categories, P values represent overall comparisons between males and females across all categories of the variable. $P < 0.05$ was considered statistically significant.

Correlations among circadian, anthropometric, sleep, and lifestyle variables

The correlation analysis is presented in Figure 1. The correlation analysis showed that higher rMEQ scores were negatively correlated with BMI ($\varrho = -0.138$, $P < 0.001$), waist circumference ($\varrho = -0.136$, $P < 0.001$), waist–hip ratio ($\varrho = -0.129$, $P < 0.001$), central obesity ($\varrho = -0.087$, $P < 0.05$), and body fat percentage ($\varrho = -0.074$, $P < 0.05$). Social jetlag was positively correlated with diastolic blood pressure ($\varrho = 0.130$, $P < 0.001$). Average sleep duration was positively correlated with rMEQ score ($\varrho = 0.128$, $P < 0.001$). Waist circumference was strongly positively correlated with central obesity ($\varrho = 0.775$, $P < 0.001$), hip circumference ($\varrho = 0.618$, $P < 0.001$), and waist–hip ratio ($\varrho = 0.562$, $P < 0.001$).

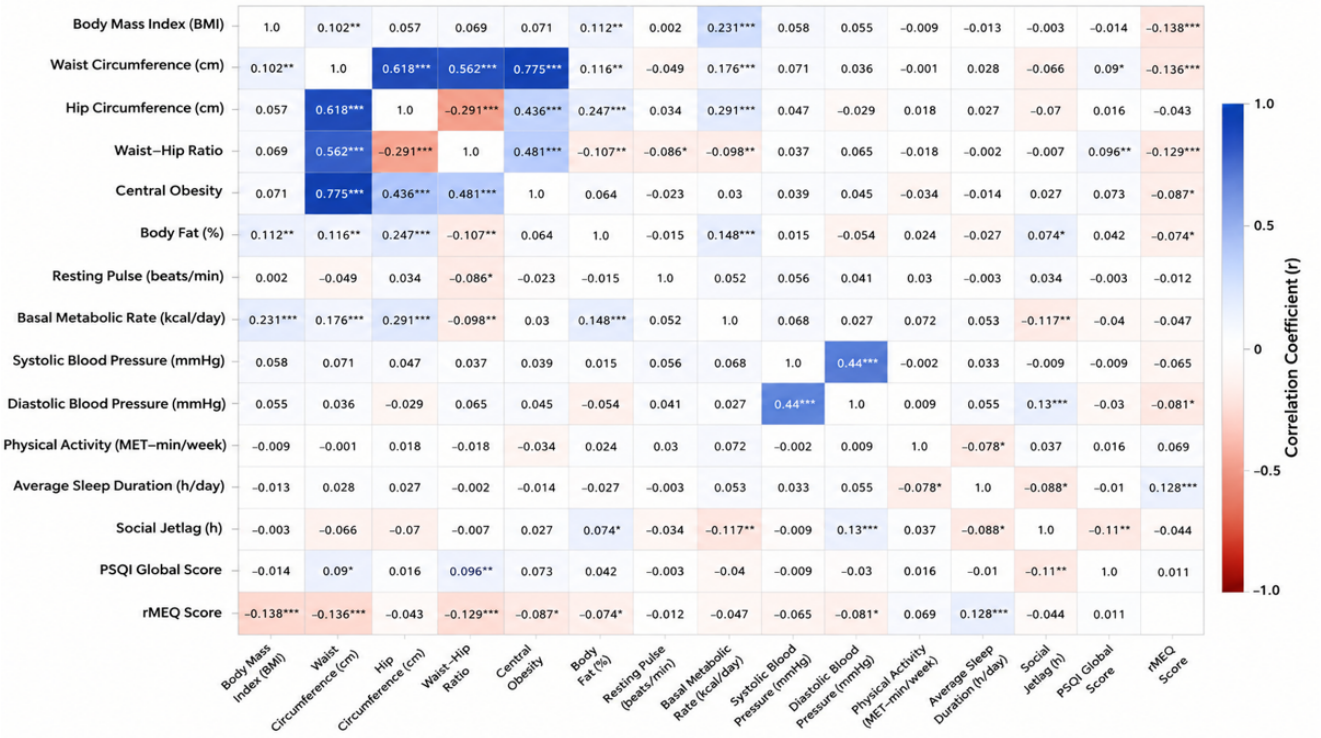

Figure 1. Spearman's rank correlation heatmap of anthropometric, metabolic, sleep, circadian, and physical activity variables among adults in Tamil Nadu, India (N = 720). Values represent Spearman's correlation coefficient (ϱ). Asterisks indicate statistical significance: $P < 0.05$, $P < 0.01$, and $P < 0.001$.

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Factors associated with BMI

The adjusted regression coefficients, 95% confidence intervals, and P values for all predictors included in the multivariable BMI model are presented in Figure 2. Social jetlag, average sleep duration, PSQI global score, breakfast skipping, dietary energy intake, and physical activity were not independently associated with BMI after adjustment for the other model covariates. The overall multivariable regression model was statistically significant ($F(13, 706) \approx 2.619$, $P \approx 0.0014$) and explained approximately 4.6% of the variance in BMI ($R^2 = 0.046$; adjusted $R^2 \approx 0.028$). In the sensitivity analysis restricted to employed participants (n = 649), higher rMEQ scores remained inversely associated with BMI (B = −0.179, 95% CI: −0.316 to −0.042; P = 0.011), consistent with the direction of the association in the overall sample.

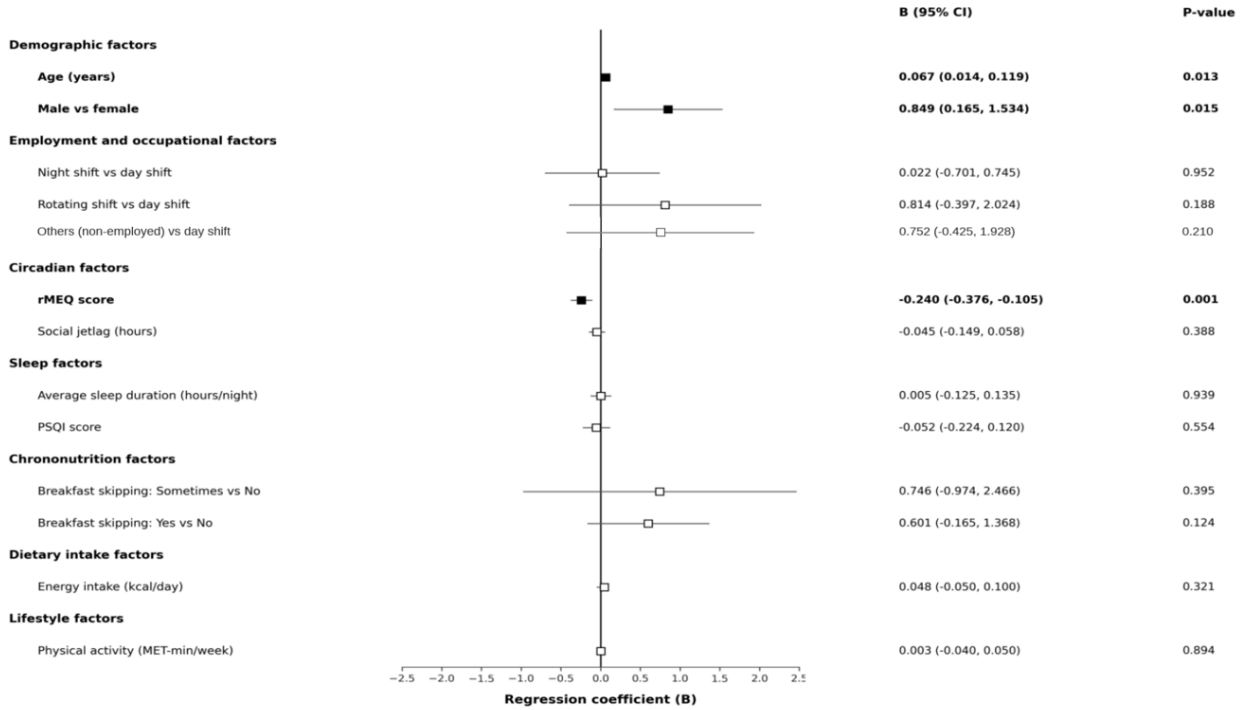

Figure 2. Multivariable linear regression analysis of factors associated with BMI.

Model: n = 720; $R^2 = 0.046$; adjusted $R^2 \approx 0.028$; $F(13, 706) \approx 2.619$; model $P \approx 0.0014$. Footnotes: B, unstandardized regression coefficient; CI, confidence interval; PSQI, Pittsburgh Sleep Quality Index; rMEQ, reduced Morningness–Eveningness Questionnaire; MET, metabolic equivalent of task. Day-shift workers were the reference category for occupational work schedule, and female participants were the reference category for gender. Energy intake is expressed per 100 kcal/day increase, and physical activity is expressed per 100 MET-min/week increase. Positive B values indicate higher BMI, whereas negative B values indicate lower BMI. Statistical significance was set at $P < 0.05$.

Circadian preference and measures of adiposity

The association with morningness was also observed for central adiposity (Table 2). Higher rMEQ scores were independently associated with lower waist circumference (B = −0.660 cm, 95% CI: −0.991 to −0.329; $P < 0.001$) after adjustment for the specified covariates. rMEQ score was also inversely correlated with waist-to-height ratio ($\rho = -0.131$, $P < 0.001$). Compared with day-shift workers, night-shift work was not significantly associated with BMI, waist circumference, or body fat percentage. Rotating-shift work was associated with significantly higher waist circumference (B = 3.321 cm, 95% CI: 0.374 to 6.268; P = 0.027), as was the Others (non-employed) category (B = 3.376 cm, 95% CI: 0.424 to 6.328; P = 0.025). Neither rotating-shift work nor the Others category was significantly associated with BMI or body fat percentage.

Table 2. Multivariable associations of circadian preference and occupational status with adiposity outcomes (N = 720)

Adiposity outcome	rMEQ score	Night shift	Rotating shift	Others
	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
BMI (kg/m²)	−0.240	0.022	0.814	0.752
	(−0.376 to −0.105)	(−0.701 to 0.745)	(−0.397 to 2.024)	(−0.425 to 1.928)
	P <0.001	P = 0.952	P = 0.188	P=0.210
Waist circumference (cm)	−0.660	−0.816	3.321	3.376
	(−0.991 to −0.329)	(−2.578 to 0.947)	(0.374 to 6.268)	(0.424 to 6.328)
	P <0.001	P = 0.364	P = 0.027	P=0.025
Body fat (%)	−0.241	−0.205	−1.775	−1.851
	(−0.483 to 0.001)	(−1.495 to 1.085)	(−3.933 to 0.383)	(−4.010 to 0.308) P=0.093
	P = 0.051	P = 0.755	P = 0.107	

Chronotype reflects individual preference for the timing of sleep, activity, and other daily behaviours. In the present study, higher rMEQ scores, indicating greater morningness, were independently associated with lower BMI. A similar inverse association was observed with waist circumference, suggesting that the relationship was not restricted to BMI alone. Previous studies have also linked later chronotype with less favourable dietary behaviour, body composition, and cardiometabolic characteristics (Zuraikat et al., 2021; van der Merwe et al., 2022; Baidoo & Knutson, 2023). The consistent inverse associations with BMI and waist circumference support an association between greater morningness and these measures of adiposity in the present population.

The coefficient of −0.240 kg/m² indicates that each one-point higher rMEQ score was associated with a 0.240 kg/m² lower BMI after adjustment for the other covariates, corresponding to approximately 0.7 kg/m² across the three-point difference between the evening-tendency and morning-tendency tertile cut-offs (18 versus 21), an association of modest magnitude. The confidence interval (−0.376 to −0.105) indicates that differences of between about 0.1 and 0.4 kg/m² per point are compatible with these data. Coefficients whose confidence intervals included zero, such as those for social jetlag and sleep duration, should not be read as evidence of no association, but as estimates too imprecise to establish a direction in this sample.

Several behavioural and physiological pathways may contribute to this relationship. Evening-oriented individuals may differ from morning-oriented individuals in the timing of sleep and meals, dietary choices, and daily activity patterns. Circadian disruption may also influence energy metabolism and hormonal rhythms when behavioural activities occur at biologically inappropriate times (McHill & Wright, 2017). However, these mechanisms cannot be established from the present findings. Dietary energy intake, breakfast skipping, average sleep duration, PSQI score, and physical activity were not independently associated with BMI after adjustment. Furthermore, the rMEQ measures subjective circadian preference rather than endogenous circadian phase. The findings should therefore be interpreted as associations between greater morningness and lower BMI and waist circumference, rather than evidence of a direct biological effect of circadian phase on body weight.

In contrast to circadian preference, occupational work schedule was not independently associated with BMI. Neither permanent night-shift nor rotating-shift work showed an independent association with BMI compared with day-shift work. This differs from previous evidence linking shift work with overweight, obesity, and abdominal obesity (Proper et al., 2016; Liu et al., 2018; Sun et al., 2018). Other reviews have suggested that circadian disruption, sleep disturbance, and metabolic alterations may contribute to the adverse health consequences associated with shift work (Antunes et al., 2010; Kervezee et al., 2020; Boivin et al., 2022; Silva & Costa, 2023; Schettini et al., 2023).

Although work schedule was not associated with BMI, rotating-shift workers and non-employed participants had about 3.3 cm higher waist circumference than day-shift workers. These estimates were imprecise (small groups, wide confidence intervals, no multiplicity correction) and should be regarded as hypothesis-generating.

The occupational comparisons were pairwise contrasts against day-shift workers (n = 322), with permanent night-shift (n = 272), rotating-shift (n = 55), and non-employed (n = 71) participants as contrast groups; no omnibus test of the occupational variable was conducted, and no adjustment was made for the three simultaneous contrasts. The rotating-shift and non-employed estimates derive from the two smallest groups, and their confidence intervals (0.374 to 6.268 cm and 0.424 to 6.328 cm) approach zero at the lower bound, so the data are compatible with differences ranging from negligible to clinically relevant. The non-employed category combined homemakers and unemployed adults, two groups likely to differ in daily routine and activity, and was retained as a single category only because of limited numbers; the corresponding estimate should therefore not be read as an effect of non-employment as such. Chrononutrition contrasts across schedules, including late-night snacking, first-meal timing, and eating-window duration, were likewise overall group comparisons without post-hoc pairwise correction.

Occupational work schedule, chronotype, and BMI

The distribution of chronotype across occupational work schedules was examined separately within BMI categories among the 649 employed participants. No association was observed among participants with normal weight ($\chi^2 = 1.246$, $P = 0.871$, Cramér's V = 0.048), Grade 1 obesity ($\chi^2 = 3.069$, $P = 0.546$, Cramér's V = 0.140), or Grade 2 obesity ($\chi^2 = 0.652$, $P = 0.957$, Cramér's V = 0.122). An association was observed in the overweight category ($\chi^2 = 21.721$, $P < 0.001$), although the effect size was small (Cramér's V = 0.203). Statistical testing was not performed for the underweight category because of insufficient cell counts.

The exploratory analysis showed a significant difference in chronotype distribution across occupational schedules among participants with overweight, whereas no significant association was observed among those with normal weight or in the higher obesity categories. However, relatively small numbers in some BMI strata reduced statistical precision. These findings should therefore be considered exploratory and should not be interpreted as evidence that the relationship between occupational schedule and chronotype systematically differs according to BMI category.

Occupational work schedule and chrononutrition

Chrononutrition characteristics according to occupational work schedule are presented in Table 3. The distribution of the main meal of the day differed across work schedules (P = 0.028). Meal-skipping behaviour did not differ significantly across occupational work schedules ($\chi^2(4) = 4.013$, P = 0.404). Late-night snacking differed significantly across work schedules (P < 0.001) and was reported by 40.4% of night-shift workers, compared with 22.0% of day-shift and 23.6% of rotating-shift workers. First-meal timing differed across groups (P < 0.001), with rotating-shift workers reporting the latest first meal (9.65 ± 0.93 h). Last-meal timing did not differ significantly across occupational work schedules ($F(2, 646) \approx 0.780$, $P \approx 0.459$). Eating-window duration differed significantly across groups (P < 0.001) and was shortest among rotating-shift workers (10.69 ± 1.88 h), compared with night-shift (11.83 ± 1.85 h) and day-shift workers (12.10 ± 1.31 h). These findings describe overall differences and do not establish statistical significance for individual pairwise comparisons. Thus, differences across occupational schedules were more apparent for the timing and distribution of eating than for meal skipping.

Table 3. Chrononutrition characteristics according to occupational work schedule among employed participants (n = 649)

Variable	Day Shift (n=322)	Night Shift (n=272)	Rotating Shift (n=55)	Test statistic	df	P-value
Meal Pattern						
Main Meal of the Day, n (%)						
Breakfast	101 (31.4)	76 (27.9)	25 (45.5)	14.301	6	0.028
Lunch	164 (50.9)	144 (52.9)	29 (52.7)			

Dinner	56 (17.4)	49 (18.0)	1 (1.8)			
Snacks	1 (0.3)	3 (1.1)	0 (0.0)			
Meal Skipping, n (%)						
Yes	85 (26.4)	82 (30.1)	12 (21.8)	4.013	4	0.404
No	235 (73.0)	190 (69.9)	43 (78.2)			
Sometimes	2 (0.6)	0 (0.0)	0 (0.0)			
Late-night Snacking, n (%)						
Yes	71 (22.0)	110 (40.4)	13 (23.6)	24.921	2	<0.001
No	251 (78.0)	162 (59.6)	42 (76.4)			
Meal Timing						
First Meal Time (h)	8.56 ± 0.90	8.57 ± 1.14	9.65 ± 0.93	29.080	2	<0.001
Last Meal Time (h)	20.51 ± 1.51	20.36 ± 1.58	20.34 ± 1.82	0.789	2	0.459
Eating-window Duration (h)	12.10 ± 1.31	11.83 ± 1.85	10.69 ± 1.88	18.20	2	<0.001

Footnotes: Values are presented as n (%) for categorical variables and mean ± SD for continuous variables. Categorical variables were compared using Pearson's chi-square test (χ^2); Monte Carlo exact P values were used where expected cell counts were <5 (main meal of the day, meal skipping). Continuous variables were compared using one-way ANOVA (F). $P < 0.05$ was considered statistically significant.

Occupational work schedules were associated with differences in several chrononutrition characteristics, despite the absence of an independent association with BMI. Late-night snacking differed significantly across occupational groups and was reported most frequently among permanent night-shift workers. Significant overall differences were also observed in first-meal timing and the reported eating interval, with rotating-shift workers showing the latest first meal and shortest interval descriptively. These findings are consistent with previous studies documenting differences in eating behaviours and meal timing among shift workers (Almajwal, 2016; Bonham et al., 2016; Hemmer et al., 2021). However, as corrected pairwise comparisons were not performed, the overall group differences should not be interpreted as evidence that every occupational group differed significantly from the others.

These findings are relevant to chrononutrition, which considers the timing of food intake in addition to the amount and composition of the diet. The timing and distribution of food intake in relation to the circadian system have increasingly been considered relevant to energy balance and metabolic regulation (Basolo et al., 2021; Flanagan et al., 2021; Raji et al., 2024; Reytor-González et al., 2025). More recent research has also emphasized eating windows and temporal dietary patterns in populations exposed to non-standard work schedules (Chatterjee & Sahu, 2026; Alotaibi, 2026).

The greater frequency of late-night snacking among night-shift workers may reflect the temporal demands of working during hours normally allocated to sleep. Similarly, the later first meal and shorter eating window among rotating-shift workers may reflect the changing temporal demands of rotating schedules. These differences suggest that occupational schedules may be more clearly related to when food is consumed than to overall adiposity. However, altered meal timing should not be considered a mediator of the relationship between occupational schedule and BMI because mediation was not tested and work schedule itself was not independently associated with BMI.

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Dietary intake according to occupational work schedule

Mean daily macronutrient and micronutrient intakes according to occupational work schedules are shown in Figure 3 and Figure 4. Total energy intake did not differ significantly among day, night, and rotating-shift workers ($P = 0.233$). No significant differences were observed for carbohydrate, protein, total fat, or fibre intake. Calcium, phosphorus, zinc, iron, and vitamin E intake were also comparable across work schedules.

Differences were observed for vitamin C ($P = 0.004$), β-carotene ($P < 0.001$), folate ($P = 0.012$), and α-linolenic acid ($P = 0.007$). The corresponding effect sizes were small ($\eta^2 = 0.017$, 0.027, 0.014, and 0.015, respectively). Given the number of nutrient comparisons and the use of a single 24-hour dietary recall, these differences were treated as exploratory rather than as evidence of broad differences in dietary intake between occupational groups.

The dietary intake findings provide further context to the chrononutrition results. Total energy intake was broadly comparable across occupational schedules, and carbohydrate, protein, total fat, and fibre intakes did not differ significantly. Thus, differences in meal timing occurred without corresponding differences in overall energy or macronutrient intake. This pattern suggests that the nutritional consequences associated with occupational schedules may involve the temporal distribution and selection of foods rather than simply the total quantity consumed.

Significant differences were observed for vitamin C, β-carotene, folate, and α-linolenic acid. These differences may indicate variation in food choices across occupational schedules, although specific food sources were not examined and this explanation remains speculative. Quantitative nutrient comparisons were also derived from a single 24-hour dietary recall, which may not adequately represent habitual intake or day-to-day variation, particularly among individuals with changing work schedules. In addition, the number of nutrient comparisons increases the possibility of chance findings. These selected nutrient differences should therefore be considered exploratory rather than evidence of systematic differences in habitual dietary intake.

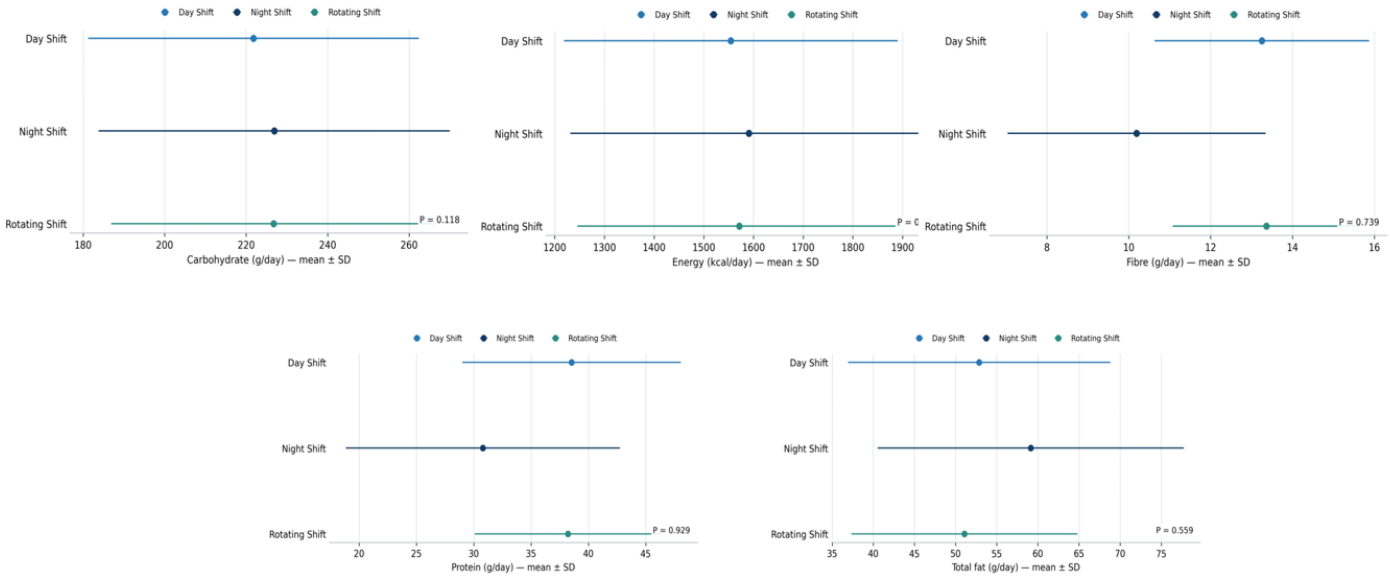

Figure 3. Daily energy and macronutrient intake according to occupational work schedule (n = 649)

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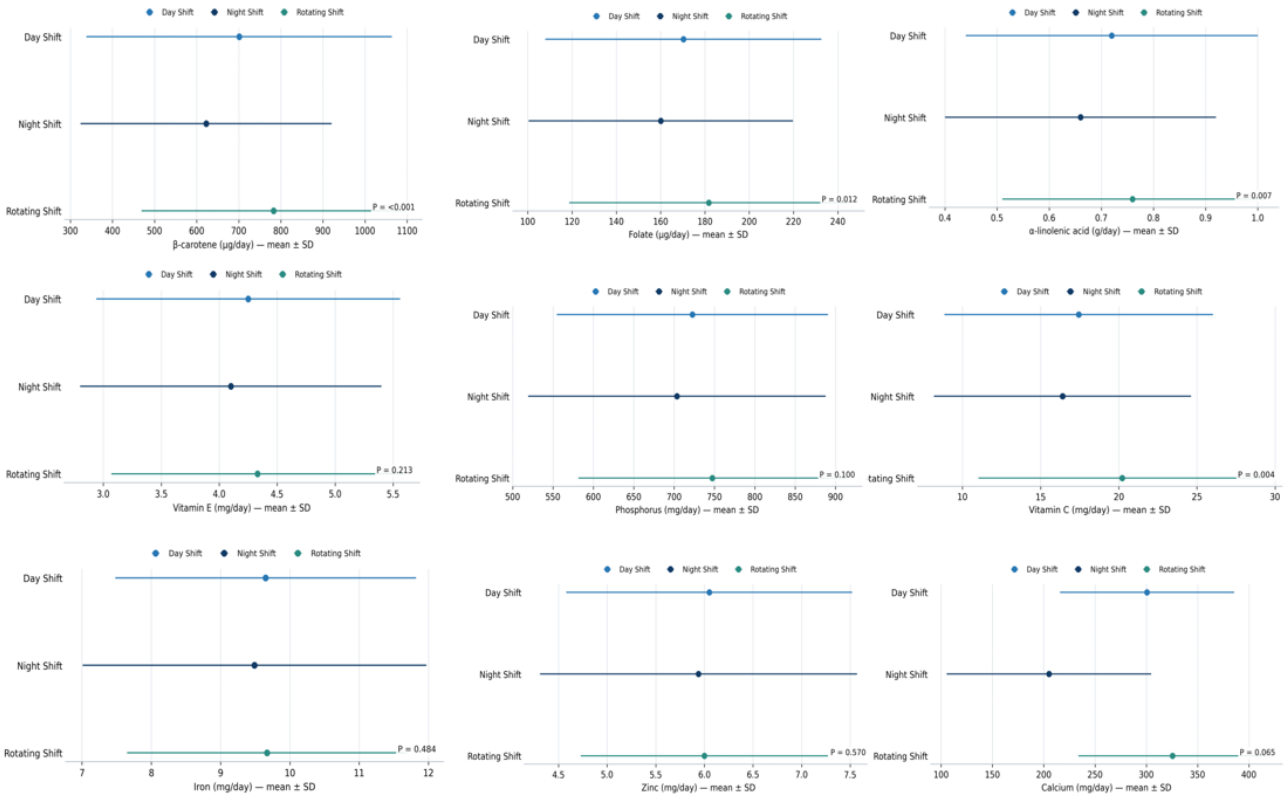

Figure 4. Daily micronutrient intake according to occupational work schedule (n = 649)

Social jetlag was not independently associated with BMI. This differs from previous research linking social jetlag with obesity and metabolic outcomes (Wittmann et al., 2006; Roenneberg et al., 2012; Brum et al., 2020; Li et al., 2022). Morningness and social jetlag represent related but distinct aspects of circadian behaviour. Morningness reflects an individual's preferred timing, whereas social jetlag reflects the discrepancy between sleep timing on work and free days (Taillard et al., 2021). In the present study, morningness remained independently associated with BMI whereas social jetlag did not.

The only association observed for social jetlag was a weak positive correlation with diastolic blood pressure ($\varrho = 0.130$, $P < 0.001$), which was unadjusted, small in magnitude, and one of many correlations examined; it should therefore be regarded as exploratory rather than as evidence that social jetlag raises blood pressure. Because social jetlag was computed as an absolute difference, it does not distinguish workday sleep restriction from free-day sleep extension, and in a sample in which 41.9% of employed participants worked permanent night shifts, the measure may capture schedule inversion rather than the delayed-phase misalignment it is intended to reflect. Social jetlag should accordingly be interpreted here as a crude indicator of workday–free-day sleep-timing discrepancy, and its null association with adiposity as specific to this operationalisation and sample rather than as a general absence of association.

Average sleep duration, PSQI score, and physical activity were also not independently associated with BMI after adjustment. These findings should not be interpreted as indicating that sleep and physical activity are unimportant for obesity. Rather, among the variables considered simultaneously in the present model, circadian preference showed the clearest independent association with BMI.

Sleep duration and physical activity warrant consideration because both may act as potential confounders or mediators of the association between circadian preference and adiposity. Average sleep duration was positively correlated with rMEQ score ($\varrho = 0.128$, $P < 0.001$), suggesting that differences in sleep duration may be related to circadian preference. Adjustment for sleep

duration may therefore have influenced the estimated association between morningness and adiposity, although the direction and magnitude of this influence cannot be established from the present cross-sectional analysis. Furthermore, sleep duration and physical activity were assessed using self-reported measures and may be subject to measurement error. Such errors may have attenuated or otherwise distorted the estimated associations and contributed to residual confounding. The limited variance explained by the BMI model ($R^2 = 0.046$) indicates that the variables included in the analysis accounted for only a small proportion of the observed differences in BMI.

Differences between previous findings and the present study may be related to variation in occupational populations, definitions of shift work, duration and intensity of shift exposure, working hours, socioeconomic characteristics, and adjustment for potential confounders. Stress, sleep disruption, circadian misalignment, and behavioural changes have been proposed as interconnected pathways through which occupational schedules may influence metabolic health (Golding et al., 2022). In the present analysis, work schedule was considered simultaneously with individual morningness, social jetlag, sleep, dietary intake, and physical activity. This may partly explain why occupational schedule did not show an independent association with BMI.

Because exposures and outcomes were measured simultaneously, the direction of these associations cannot be determined. Lower adiposity may predispose individuals towards morning-oriented routines, adults with higher adiposity may preferentially select or remain in particular work schedules, and shared genetic, familial, or socioeconomic factors may contribute to both circadian preference and body composition. All associations reported here should therefore be read as cross-sectional and hypothesis-generating.

Several limitations of the study should be considered. The cross-sectional design does not allow the temporal sequence of the observed associations to be determined, and causal relationships cannot be established. Circadian preference, dietary intake, meal timing, sleep, and physical activity were partly based on self-report and may therefore be affected by recall and reporting errors. Quantitative nutrient intake was based on a single 24-hour dietary recall and may not represent habitual intake. Although snack timing was recorded, the eating window was derived from breakfast and dinner times only and therefore underestimates the full duration of daily energy intake; this underestimation is likely greatest among night-shift workers, 40.4% of whom reported late-night snacking. Between-group differences in eating-window duration should accordingly be interpreted as differences in the span of main meals rather than in total daily eating duration.

The rMEQ assesses subjective morningness rather than physiological circadian phase, and objective markers such as dim-light melatonin onset were not available. The degree of alignment between individual circadian preference and occupational schedule was not objectively assessed. Finally, relatively small numbers in some work-schedule and BMI subgroups reduced the precision of the exploratory analyses. The BMI model explained only 4.6% of the variance (adjusted $R^2 \approx 0.028$), indicating that the included predictors accounted for a relatively small proportion of the variation in BMI. Multiple outcomes and nutrient comparisons were tested without correction for multiplicity, so borderline findings may be due to chance. Participants were recruited by non-probability sampling in four districts, and the findings may not be generalisable to all adults in Tamil Nadu or India.

For night-shift workers, whose waking hours extend beyond 21:00 by schedule, the clock-time criterion may classify eating during working hours as late-night snacking, so the higher prevalence in this group may partly reflect the definition. Socioeconomic position, smoking, and alcohol use were not included in the models, so residual confounding is possible, and adjusting for sleep and social jetlag may have attenuated the association of work schedule with BMI. In addition, participation required availability during data-collection visits, and adults with the most irregular or demanding schedules may have been less likely to take part, which could bias occupational comparisons in an unpredictable direction. Because employment status was ascertained at a single time point, current schedule may not reflect cumulative shift-work exposure, and reverse selection, whereby adults with existing weight or metabolic problems move away from or towards particular schedules, cannot be excluded. Dietary intake, meal timing, and sleep variables were collected by interviewer-administered questionnaire, so social-desirability bias, particularly under-reporting of energy intake and of late-night eating, is also possible. Body fat percentage was estimated by handheld bioelectrical impedance, which is sensitive to hydration status and provides only an approximate measure of adiposity. Educational attainment, household income, smoking, and alcohol use were recorded but were not included in the regression models; residual confounding by socioeconomic position and by these behaviours therefore cannot be excluded. Finally, the four districts were purposively selected for regional spread and the sample was urban and semi-urban, so rural adults and other Indian states are not represented.

Future prospective studies should incorporate objective measures of circadian phase, detailed information on the duration and history of shift-work exposure, repeated assessments of dietary intake and meal timing, longitudinal measures of BMI and central adiposity, and fuller adjustment for socioeconomic and lifestyle confounders in larger, probability-based samples. Such studies could clarify whether individual circadian characteristics and occupational schedules interact over time and whether chrononutrition-related behaviours contribute to subsequent changes in metabolic health.

CONCLUSION

Greater morningness was independently associated with lower BMI and waist circumference among adults in Tamil Nadu, although the associations were modest in magnitude. Occupational work schedule was not independently associated with BMI, but differences in eating patterns were observed across work-schedule groups.Night-shift workers more frequently reported late-night snacking, while rotating-shift workers had the latest first-meal timing and shortest eating-window duration descriptively. Total energy and macronutrient intakes were broadly comparable across occupational groups. These findings suggest that circadian preference and occupational work schedules may be associated with different aspects of adiposity and eating behaviour. However, the cross-sectional design, self-reported behavioural measures, potential residual confounding, and limited explained variance restrict causal interpretation. Prospective studies incorporating objective circadian assessments, repeated dietary measurements, and detailed occupational exposure histories are needed to clarify these relationships and inform future chrononutrition interventions.

DECLARATIONS STATEMENT

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Conflict of Interest

The authors have no competing interests to declare that are relevant to the content of this article.

Ethics Approval

The study protocol was approved by the Institutional Human Ethics Committee of the PSG Institute of Medical Sciences & Research (PSG/IHEC/2026/Appr/Exp/329) before participant recruitment. All study procedures complied with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from each participant prior to enrolment. Participants received a detailed explanation of the study objectives and procedures. Participation was voluntary, and confidentiality was maintained by assigning unique identification numbers and securely storing all participant information.

Consent to participate

Written informed consent was obtained from all individual participants included in the study.

Use of artificial intelligence

During the preparation of this manuscript, the authors used artificial intelligence (AI) tools to assist with manuscript development, including language editing, grammar correction, improvement of clarity and readability, organization and presentation, and review of tables, figures, statistical reporting, and interpretation. All AI-assisted outputs were critically reviewed, verified against the original study data, statistical analyses, and relevant literature, and edited by the authors. The authors take full responsibility for the accuracy, integrity, originality, and scientific conclusions of the manuscript. AI tools were not used to collect the study data or independently determine the study findings or conclusions.

Authors' contributions

Harinivashini Murugesan contributed to the study conception and design, data collection, data analysis and interpretation, and manuscript preparation. Anusuya Devi Kuppuswamy contributed to study supervision, interpretation of the findings, critical revision of the manuscript, and final approval of the version to be published. Both authors approved the final manuscript and agree to be accountable for all aspects of the work.

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